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An Impact and Penetration Effects Study

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DEPUTY FOR AEROSPACE SYSTEMS TEST

AIR PROVING GROUND CENTER

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

(Prepared under Contract No. AF 08(635)-975 by
the Aerojet-General Corp. Author: J. E. Ferguson)

FOREWORD

The Ordnance Division of Aerojet-General Corporation takes pleasure in presenting this special technical report to the Deputy for Aerospace, Air Proving Ground Center, Eglin Air Force Base, Florida. This report contains portions of the results of experimental research on hypervelocity impact effects in the velocity regime from 29,000 to 39,000 feet per second.

This research was conducted under Contract AF 08(635)-975. Mr. Andrew Bilek of the Ballistics Branch, Directorate for Aerospace, is the Aerospace Project Manager.

Employment of the Shaped Charge Hypervelocity Projectile Accelerator technique requires very conscientious effort. The results presented herein would not have been possible without the careful and skillful direct effort and contributions of R. N. Jonnum, R. R. Randall, W. A. Rhea III, D. R. Bayer, G. R. Czarnomski, M. H. Lowery, and F. O'Dell Jr.

The author wishes also to acknowledge the technical guidance and consultations of L. Zernow and K. N. Kreyenhagen.

ABSTRACT

The Shaped Charge Hypervelocity Projectile Accelerator is being used to study impact and penetration effects upon various thicknesses of targets at velocities between 24,000 and 39,000 feet per second. This Special Report presents and analyzes 208 data points gathered for impacts in the 29,000-33,000 feet per second velocity range, with 0.03-0.8 gram aluminum projectiles against 0.375-inch, 0.500-inch, 1.00-inch and 4.0-inch thick 2024-T4 aluminum target plates; 19 data points gathered for impacts in the 35,000-39,000 feet per second velocity range with 0.01-0.7 gram aluminum projectiles against 0.100-inch thick 2024-T4 aluminum target plates; and 63 data points gathered for impacts in the 22,000-26,000 feet per second velocity range with 0.02-0.7 gram copper projectiles against 0.100-inch thick 2024-T4 aluminum target plates and 0.500-inch thick soft copper target plates. Angles of obliquity between the velocity and the target surface for these experiments were 90°, 50° and 20°. Curves, photographs, and flash radiographs illustrating the data are presented.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

MORRILL E. MARSTON
Colonel, USAF
Deputy for Aerospace Systems Test

CONTENTS

1. INTRODUCTION

Under Contract AF 08(635)-975, the Shaped Charge Hypervelocity Projectile Accelerator is being used to obtain impact data against various types of targets in the velocity regime from 29,000 to 39,000 feet per second (8.8 to 11.9 km/sec) for aluminum projectiles and from 22,000 to 30,000 ft/sec (6.7 to 9.1 km/sec) for copper projectiles.

This is the third in a series of special reports being issued to describe the experimental and analysis techniques and to present the data obtained. The work performed under the Technique Development Phase of the contract has been presented in Reference 1 and outlines the development of the basic shaped charge projector and associated instrumentation and data analysis techniques. The second special report, Reference 2, presented data and analysis for penetration of 0.100-inch aluminum plates by aluminum projectiles at velocities of 29,000 to 33,000 ft/sec (8.8 to 10.1 km/sec).

This special report presents and analyzes the results of a group of experiments which have been conducted to study the impacting of thick and semi-infinite aluminum targets by aluminum projectiles at 29,000 to 33,000 ft/sec (8.8 to 10.1 km/sec). Included also are the results of the exploratory testing with aluminum projectiles impacting 0.100-inch aluminum targets at velocities of 35,000 to 39,000 ft/sec (10.7 to 11.9 km/sec), and copper projectiles impacting 0.100-inch aluminum targets and 0.500-inch copper targets at velocities of 22,000 to 30,000 ft/sec (6.7 to 9.1 km/sec).

2. DESCRIPTION OF TECHNIQUE

The technique developed by Aerojet to obtain terminal ballistics data for projectiles impacting in the 29,000-39,000 ft/sec velocity range utilizes the explosive shaped-charge. The shaped-charge, developed primarily as a penetration device for military application, accelerates a jet of metal to very high velocities through the collapse of a metal liner under the detonation pressure from the explosive. Velocity gradients in the jet cause it to separate into individual particles. For effectiveness as a penetration device, these particles ideally strike a target at nearly the same point of impact.

To adapt the shaped-charge to hypervelocity terminal ballistics investigations requires that techniques be used to (1) separate the particles of the jet so that independent impacts can be observed and (2) determine individual projectile characteristics just prior to impact at the target. Individual impacts at the target are obtained by asymmetric initiation of

the shaped-charge. The jet particles are separated axially by the aforementioned velocity gradients. The asymmetric initiation causes the particles to fan out radially, thus providing independent impacts on the target.

Since the individual projectiles are formed at random by the separation of the shaped-charge jet, little control is exercised over fragment shape and mass, other than that which results from the charge size and the liner material properties. It is therefore necessary to determine individual projectile characteristics just prior to impact at the target. This is accomplished by taking two pairs of orthogonal flash radiographs. One pair at a station 4.5 feet upstream from the target and the other pair at the target surface. Projectile shape, mass, velocity and orientation are determined by measurements from these radiographs. Fiducial markings on or near the target appear in the radiographs and assist in the correlation of the projectiles and the craters or holes produced on the target plate.

3. TERMINAL BALLISTICS DATA

3.1 THICK ALUMINUM TARGETS

Shaped charge hypervelocity investigations were conducted with aluminum projectiles impacting thick aluminum targets (i.e., targets whose thickness is on the order of the depth of craters which would be formed in semi-infinite targets). These investigations were conducted against 0.375-inch, 0.500-inch and 1.00-inch 2024-T4 aluminum plates.

The shaped charge projector design shown in Figure 1 was employed for these investigations. This projector was Composition B cast loaded and employed a 42° aluminum liner. Eccentric initiation was used for projectile dispersion.

One hundred and thirty-seven data points were obtained from these investigations. Projectile masses ranged from 0.4 to 11.5 grains (0.03 to 0.07 grams). Projectile velocities ranged from 29,000 to 33,000 ft/sec (8.8 to 10.1 km/sec).

3.1.1 Normal Incidence

Investigations with aluminum projectiles impacting thick aluminum targets positioned at 90° to the impact velocity produced a total of 84 data points. These data are presented in Tables 1, 2, and 3. Close-up photographs of the target impact areas for these tests are shown in Figures 2 through 23.

3.1.2 Oblique Incidence

Investigations with thick aluminum target positioned at angles of 50° to the impact velocity produced a total of 43 data points. These data are presented in tables 4, 5 and 6. Close-up photographs of the target impacts are presented in Figures 24 through 34.

Investigations with thick aluminum targets positioned at a 20° impact angle to the velocity were conducted only with 0.375-inch and 0.500-inch targets. Twenty data points were obtained from these tests and are presented in tables 7 and 8. The close-up photographs of the target impact areas are shown in Figures 35 through 41.

3.1.3 Residual/Spall Fragments

Figures 42 through 47 present flash radiographs showing the residual/spall* envelope at various stages of penetration for thick aluminum targets at 90° along with photographs of some of the target plates being impacted. These are separate tests since the instrumentation available at this time did not permit the determination of projectile characteristics and penetration studies to be conducted simultaneously. For determining residual/spall velocities, projectile travel time was monitored between the target plate and a backup plate parallel to the target. Travel time was measured electronically between foil switch make circuits on the target and the backup plate. Some tests were monitored by framing camera coverage to assist in the determination of residual/spall velocities.

The investigations conducted with thin 0.100-inch aluminum targets showed residual/spall velocities to be slightly less than the impacting projectile velocities. An impacting projectile velocity of 31,000 ft/sec would produce residual/spall velocities of 25,000 to 29,000 ft/sec. With thick aluminum targets, an impacting projectile velocity of 31,000 ft/sec yielded a residual/spall velocity range of 5,000 to 15,000 ft/sec for 0.375-inch and 0.500-inch aluminum targets, dependent on projectile mass and orientation at impact. With the 1.00-inch aluminum targets a 31,000 ft/sec impacting velocity produced a residual/spall velocity range of 2,000 to 12,000 ft/sec, dependent on the degree of penetration in the 1.00-inch target plate.

Figure 48 presents a framing camera sequence for impacts against a 0.500-inch thick aluminum target (Test M-316). Figure 49 shows the rear surface of the target plate and also the backup plate from this test.

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* The term residual/spall is used since for most tests it was not possible to distinguish between the residual projectile particles and the target spall particles.

Figures 50 and 51 show framing camera sequences for 1.00-inch aluminum targets. In Figure 50 a single spall impact is observed on the backup plate after 28 μsec, yielding a spall velocity of 9,600 ft/sec for this test. In Figure 51 no impact is observed on the backup plate after 68 μsec of writing time by the camera. An electronic time of 142 μsec was recorded for this test and a residual/spall velocity of 1,600 ft/sec. Figures 52 through 58 present flash radiographs of the residual/spall envelope at various stages of penetration for the oblique targets. Residual/spall velocities were measured only for 0.500-inch target plates at oblique incidence. These investigations indicated residual/spall velocities of 13,000 to 22,000 ft/sec for targets at a 50° impact angle and 7,000 to 24,000 ft/sec for a 20° impact angle, indicating residual/spall velocities to be higher for oblique target than targets at normal incidence. These velocities were computed based on electronic time measurements between parallel plates and could not be verified by framing camera coverage due to setup limitations for oblique targets inside the high altitude chamber.

3.2 SEMI-INFINITE ALUMINUM TARGETS

Shaped charge hypervelocity investigations were made with aluminum projectiles impacting semi-infinite aluminum targets (i.e., target thickness sufficient to prevent spall from the back surface of the target plate). The investigations were conducted against 4.0-inch thick 2024-T4 aluminum plates positioned at 90° to the impact velocity.

Seventy-one data points from these investigations are presented in Table 9. Closeup photographs of the target craters are shown in Figures 59 through 69.

These investigations were conducted with the shaped charge hypervelocity projectile accelerator shown in Figure 1, employing the 42° aluminum liner. Projectile masses ranged from 0.7 to 9.2 grains (0.04 to 0.58 grams) and projectile velocities ranged from 27,000 to 34,000 ft/sec (8.2 to 10.4 km/sec).

3.3 EXPLORATORY INVESTIGATIONS

3.3.1 Aluminum Projectiles, 35,000 to 39,000 ft/sec

Nineteen data points for experiments conducted with aluminum projectiles impacting thin aluminum targets (i.e., target thickness on the order of the diameter of the impacting projectiles) are presented in table 10.

These tests were conducted against 0.100-inch thick 2024-T4 aluminum plates. Closeup photographs of the target impact areas are presented in Figures 70 through 75.

These investigations were conducted with the shaped charge hyper-velocity projectile accelerator shown in Figure 76, and employed the 25° aluminum liner. Projectile masses ranged from 0.2 to 12.2 grains (0.01 to 0.8 grams). Projectile velocities ranged from 35,400 to 39,500 ft/sec (10.8 to 12.0 km/sec). This projector is still under development and difficulties were experienced with these investigations. While the desired projectile velocities were attained, the majority of the projectiles were of immeasurable shapes. Some of the larger projectiles were shown in the flash radiographs to have areas of low density Figure 77 presents flash radiographs of some of the projectiles obtained in these investigations. In view of the nebulous areas, the apparent projectile mass for these projectiles will be slightly high; however, since investigations with thin aluminum targets at 90° to the impact velocity have shown that projectile silhouette area is of more significance than projectile mass in determining target damage, the data is of some significance and is presented at this time.

3.3.2 Copper Projectiles Impacted Against Thin Aluminum Plates

Preliminary investigations with copper projectors were made against thin aluminum targets. These investigations were conducted against 0.100-inch 2024-T4 aluminum plates positioned at 90° to the impact velocity. Thirty-four data points were obtained from these investigations and are presented in Table 11. Close-up photographs of the target hole areas are shown in Figures 78 through 84.

These investigations were conducted with the shaped charge projectile accelerators shown in Figures 1 and 76 and employed both the 25° and 42° copper liners. Projectile masses ranged from 0.6 to 10.3 grains (0.04 to 0.67 grams). Projectile velocities ranged from 25,100 to 31,900 ft/sec. (7.6 to 9.7 km/sec).

3.3.3 Copper Projectiles Impacted Against Thick Copper Targets

Thirty-three data points were obtained from the investigations conducted with copper projectiles impacting thick copper targets. These tests were made against 0.500-inch copper plates positioned at 90° to the impact velocity. These data are presented in Table 12. Close-up photographs of the target impacts are shown in Figures 85 through 90.

These investigations employed the 42° copper lined shaped charge projectile accelerator shown in Figure 1. Projectile masses ranged

from 0.3 to 3.7 grains (0.02 to 0.24 grams). Projectile velocities ranged from 22,600 to 26,700 ft/sec (6.9 to 8.1 km/sec).

4. ANALYSIS AND DISCUSSION

4.1 THICK ALUMINUM TARGETS

For terminal ballistics investigations it is usually desirable to project a single, ideally shaped projectile of a predetermined mass. The investigations conducted during this program made use of a hyper-velocity projectile accelerator technique which, while producing mostly cylindrical shaped projectiles, provided a fairly wide range of L/D ratios and projectile masses. This range of projectile masses provided data in which some projectiles had sufficient momentum to perforate the target plate while others attained various degrees of penetration. As a result different types of target damage were produced by the projectiles from the shaped charge projectile accelerator. The larger projectiles impacting the thick aluminum targets produced extreme front and back surface spall or scabbing. Various degrees of spalling was encountered. Some tests produced damage in which a spall ring was completely lifted off the target front surface (Figure 3, test 543). Other tests yielded partial front spalling (Figure 14, test 534) or spalling which did not completely separate from the target surface (Figure 13, test 486). The smaller projectile masses produced mostly partial penetrations and proportional spall effects.

The quantity of data obtained under each specific target test condition was not sufficient to permit comparisons of target damage according to projectile weight groups. Since most projectiles achieved complete penetration, we have made comparisons of thick target data based on damage area excluding the spalled area.

Other investigators may be interested in damage comparisons other than the area measurements we have selected. These specific interests may be satisfied from the projectile and target characteristics and measurements listed in the tables and from the photographs presented of each target impact.

4.1.1 Normal Incidence

Plots of target damage versus projectile mass for the 0.375-inch, 0.500-inch and 1.00-inch thick aluminum targets are shown in Figures 91 through 93. All plots are made without regard for specific projectile shapes or L/D ratios. These data show that essentially the same degree of target area

damage occurs in each thickness of target for an equivalent impacting projectile mass. In each plot a best fit curve shows target damage to increase proportionally with the impacting projectile mass.

In Figure 94 a plot of target area damage versus the impacting projectile area is made for the 0.375-inch thick aluminum targets. Considerable scatter is obtained with the smaller projectile areas; however, the data approaches a fairly smooth relationship with the larger projectile areas (larger mass). The scatter with the smaller projectile areas would be expected since the larger mass of two projectiles with equivalent impacting areas would produce the larger amount of damage in the thick target. With two projectiles having equivalent impact areas, one may have sufficient mass to perforate the thick target while the other may have insufficient mass to attain complete penetration. With larger masses, where all projectiles achieve perforation, the scatter is reduced and a smooth relationship is obtained. Scatter in all plots may be partly attributed to the random orientation of the rod shaped projectiles produced by the shaped charge jet. In Figure 95 target damage area versus the impacting projectile area is plotted for the 0.500-inch thick target data. Although a definite damage trend is indicated, a less smooth relationship is obtained than with the 0.375-inch thick target data.

These data would suggest target damage for the 0.375-inch thick targets to be primarily a function of projectile mass. With the larger masses, however, where each projectile makes a clean perforation, target damage is not independent of the impacting projectile area but is determined by a combination of projectile mass and orientation (silhouette area). For targets 0.500-inch and thicker, target damage is determined primarily by projectile mass (assuming a constant impacting projectile velocity).

For any target thickness impacted by rod shaped projectiles target damage, whether determined by depth, volume or area measurement, will not be independent of projectile orientation.

A comparison of the photographs of thick target impact areas shown in Figures 2 through 23 show the damage tendency is toward the round symmetrical hole or crater regardless of projectile L/D ratios and orientation. Of interest are the photographs in Figures 96 and 97 which present a sectional view of the target plate from test M-706, a 1.00-inch thick aluminum target positioned at 90° obliquity. The front surface view of this photograph is shown in Figure 22. This target is representative of the resultant damage from hypervelocity impacts with aluminum projectiles. The shape and depth of the craters and the spall effects are evident.

Of specific interest is the area between the two craters. Notice that apparently neither crater is affected by damage from the formation of the adjoining crater even though there is only 2 inches between crater centers and 1/2 inch between adjoining crater rims.

In Figure 97, a 10 X magnification of the area between the two craters, the grain structure is undisturbed between the two craters while being severely influenced and compressed at each crater formation.

4.1.2 Oblique Incidence

For a given target it might be expected that the target damage area would increase as the target angle with the impact velocity becomes smaller, since the target surface presented to the impacting projectile area is larger than that presented on the target positioned at 90° to the impact velocity. The impact area would be larger by the factor $1/\sin\theta$, where θ is the angle between the target surface and the impact velocity. This was not found to be the case during investigations with thin targets and does not appear to be so for impacts against thick targets.

Figures 98 through 100 present graphs showing target damage area plotted against the impacting projectile mass for the 0.375-inch, 0.500-inch and 1.00-inch thick aluminum targets at 50° obliquity. A best fit curve on each plot shows target damage area to be in effect the same for each target thickness. A comparison of the damage between the 0.500-inch and 0.375-inch targets at 90° and 50° obliquity indicates target damage to be slightly less for the targets at 50° obliquity even though the target surface presented for the impacting projectile area is larger by the factor $1/\sin 50^{\circ} = 1.3$.

A fairly smooth relationship is obtained for each target thickness. Investigations with the 1.00-inch targets at 50° obliquity did not yield sufficient data points with the larger projectile masses to reliably determine the damage curve; however, the smaller projectiles appear to produce the same degree of damage as with the 0.375-inch and 0.500-inch thick targets.

A comparison of the photographs in Figures 24 through 34 show target damage for targets at 50° obliquity to tend mostly toward the round crater or hole area. Some of the larger projectiles; however, produce the oval shaped crater or hole that would be expected with an oblique impact (Figure 29, test 253; Figure 28, tests 712 and 713). The damage areas from the elongated craters is still less than that obtained with the 90° impact for an equivalent impacting projectile mass.

Figures 101 and 102 present graphs of target damage area plotted against projectile mass for the 0.375-inch and 0.500-inch thick aluminum targets at 20° obliquity. Although the data are somewhat erratic, in both plots the best fit curve shows target damage to be far less than that obtained with either the 90° and 50° target impacts even though the target surface presented to the projectile area is larger than the normal target by the factor 1/sin 20° = 2.9.

A comparison of the photographs of target damage areas for targets at 20° obliquity (Figures 35 through 41) shows different types of target damage is obtained with the target positioned at the sharper angles of obliquity.

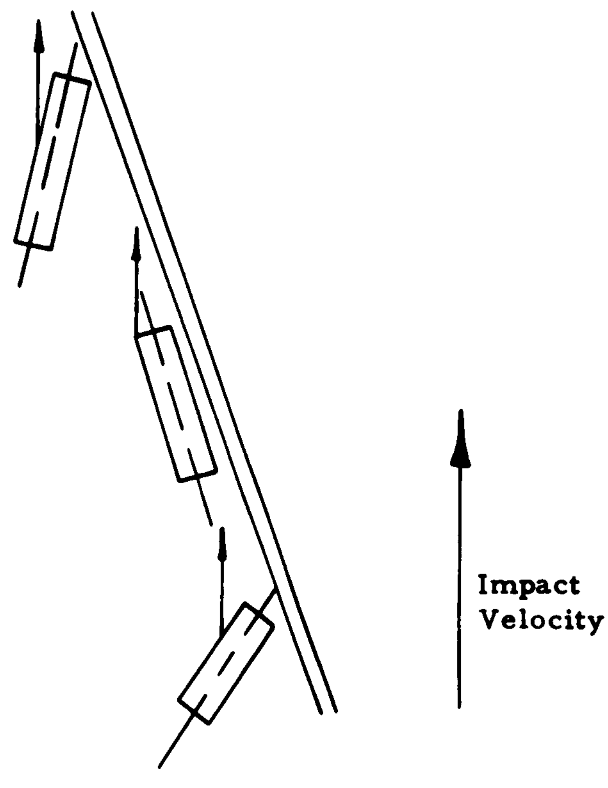
Target damage varies from complete perforations (Figure 35, test 796) to long shallow craters (Figure 37, test 811). Target damage for the sharp angles of obliquity again appears to be primarily determined by a combination of projectile mass and orientation at impact, specifically by the projectile "yaw" angle for these investigations since the angled target is pivoted on a vertical line.

The photographs presented of damage to thick targets at 20° obliquity, show that only three projectiles attained target perforation. These three target/projectile impact conditions are shown in the following illustration:

M-796A
5.2 gr, P = -10°, Y = 11°R, I = 30°

M-810A
5.5 gr, P = -4°, Y = 20°L, I = 0°

M-626A
7.7 gr, P = +3°, Y = 31°R, I = 59°



Horizontal Plane (Vertical View)
of Projectile Impacts Against a 20° Obliquity Target

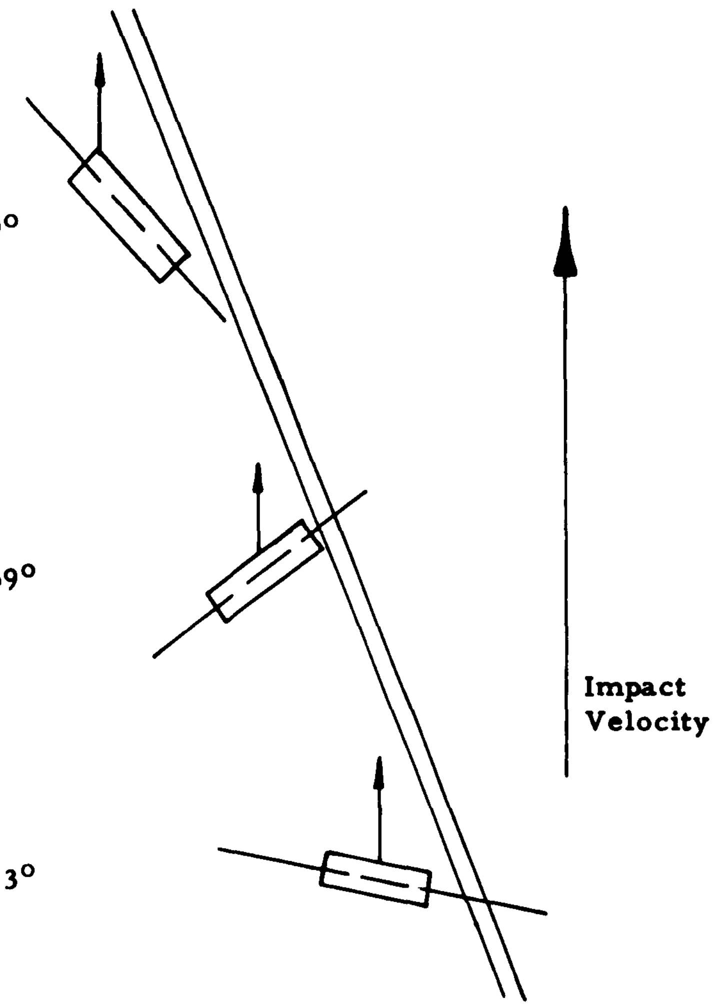
The "A" projectile from test M-796 had low pitch and yaw angles resulting in essentially an "end-on" impact by the rod shaped projectile. The "A" projectile from test M-810 impacted with 0° incidence with the target. In each of these projectile/target impact conditions a target perforation might be expected provided the projectile had sufficient momentum.

In test M-626 the "A" projectile also attained target perforation; however, the projectile/target impact conditions for this particular projectile are not unlike those presented in the following sketch of representative projectile impacts which produced the elongated shallow craters.

M - 803A
7.1 gr, $P = +5^{\circ}$, $Y = 40^{\circ}L$, $I = 20^{\circ}$

M - 795A
5.3 gr, $P = +17^{\circ}$, $Y = 52^{\circ}R$, $I = 69^{\circ}$

M - 806A
7.1 gr, $P = +87^{\circ}$, $Y = 79^{\circ}L$, $I = 13^{\circ}$



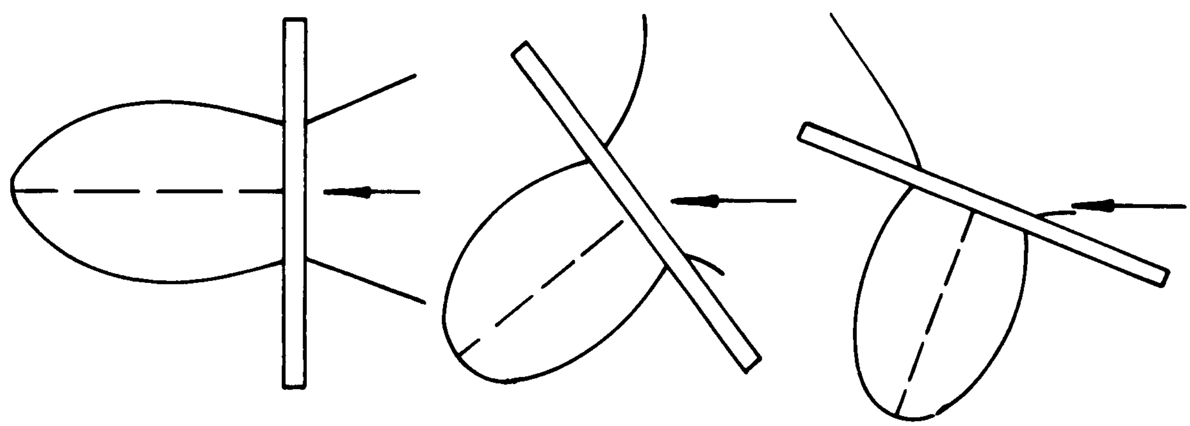
Horizontal Plane (Vertical View)
of Projectile Impacts Against a 20° Obliquity Target

Thus an unclear picture is obtained of the specific conditions which affect the degree of target damage produced by rod shaped projectiles impacting thick aluminum plates at severely oblique angles. A study of projectile/target behavior at impact would provide a more clear picture of the phenomena involved with these impact conditions. Chamber and instrumentation limitations did not permit the determination of projectile characteristics and the study of target/projectile behavior at impact to be conducted simultaneously during these investigations. It is expected that the availability of additional radiograph instrumentation will permit this study to be conducted on future experiments.

In Figure 103, a comparison plot of target damage area versus projectile mass is shown for the 0.500-inch aluminum targets at the three angles tested during this program. A relative decrease in target damage is shown as the target angle to the impact velocity becomes more acute. Target damage is shown as a straight line for each of the three angles tested to show relative target damage only and does not indicate target damage to be a linear function of impacting projectile mass. Although the number of data points collected at each target angle was sufficient to establish damage trends, it was insufficient to determine the true slope of the damage curve.

4.1.3 Residual/Spall Fragments

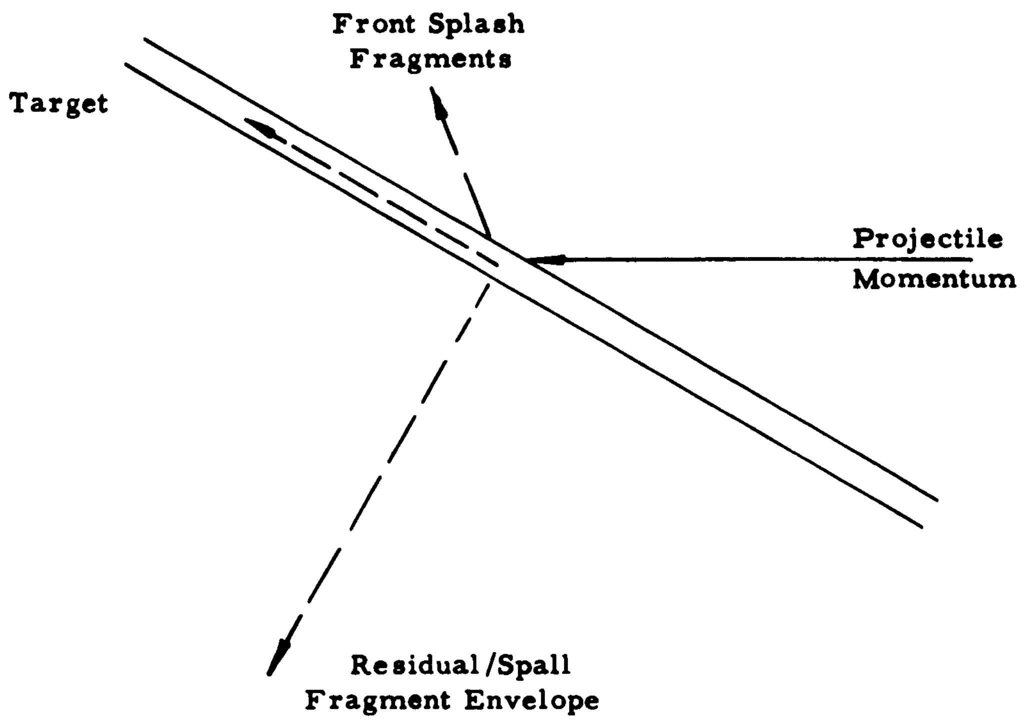
Figures 42 through 58 presented radiographs and photographs of the targets impacted for residual/spall fragment studies. As was experienced during investigations with the 0.100-inch aluminum targets, the spall fragment envelopes for thick aluminum targets appear to be nearly symmetrical about an axis which isperpendicular to the target surface and coincident with the axis of the target crater. The following sketches indicate the general nature of the fragment envelopes which are formed under the three conditions of obliquity:



90^{o} 50^{o} 20^{o}

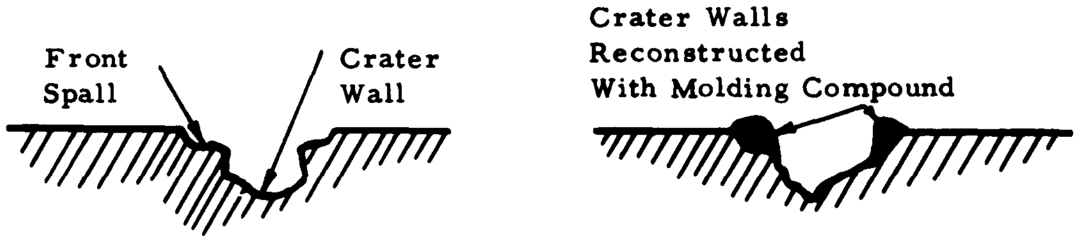
For each target angle, immediately after impact a scabbing layer accompanied by a mesh of particles is witnessed leaving the rear target surface and a fine particle splash is witnessed from the front surface (Figures 42 and 54). At various time intervals following penetration all spall and residual projectiles appear to become part of a fine mist of tiny particles which form the residual spall envelope. As was experienced with the 0.100-inch aluminum targets little or no distinction could be made between the residual projectile fragments and the target spall particles. The damage to a backup plate by these residual/spall particles is evidenced by the photograph in Figure 48, the target and backup plate from test M-316, 0.500-inch aluminum target at 90° with a 0.100-inch thick aluminum backup plate placed 6 inches behind the target.

The apparent momentum partition for the oblique target is as follows:



4.2 SEMI-INFINITE TARGETS

For investigations conducted with hypervelocity aluminum projectiles impacting semi-infinite aluminum targets, damage has been determined by measurement of crater volume, depth of penetration and crater surface area. The hard and brittle nature of the 2024-T4 aluminum results in the previously discussed frontal spallation on impact which removes the crater lips from the target producing a false crater shape. To obtain a more accurate picture of the true crater shape and measurements, the spalled area was filled in with a moulding compound and shaped to extend the existing crater wall as illustrated below:



This method of reconstruction introduces an operator error; however, the measurements obtained present a more accurate account of the true cratering effect than is otherwise obtained.

Volumes were determined by filling the crater with a measuring fluid to the original target surface. Depth measurements were made between the deepest part of the crater and the original undisturbed target surface. Area measurements are for the reconstructed crater areas as if the spalling of the crater lips had not occurred.

Figure 104 shows crater volume plotted as a function of the impacting projectile energy. It should be noted that the plot is made without regard for specific projectile shapes or in the case of cylindrical projectiles, L/D ratios. The velocity range for these investigations was relatively narrow, 29,000 - 34,000 ft/sec.

A best fit curve on the plot shows crater volume to be nearly linear for the lower projectile energies (smaller projectile mass since the velocity is in effect constant). For the higher energies (larger projectile mass) a tendency toward a sharper slope to the damage curve is indicated.

In Figure 105 crater depth is plotted against the impacting projectile mass. A linear relationship is obtained for these data with the higher projectile masses producing the deeper penetrations. Note that the upper portion of the band is composed mostly of projectiles whose incidence with the target (angle between projectile axis and target surface) greater than 45° while the lower part of the band is composed for the most part of projectiles whose incidence with the target is less than 45°. Rod shaped projectiles having incidence greater than 45° would be approaching "end-on" impact and would be expected to attain greater penetration than a side-on impact of an equivalent projectile.

In Figure 106 the data obtained from the investigations against semi-infinite aluminum targets is plotted as a function of P/d versus the impacting projectile velocity,

where: P = Depth of Penetration

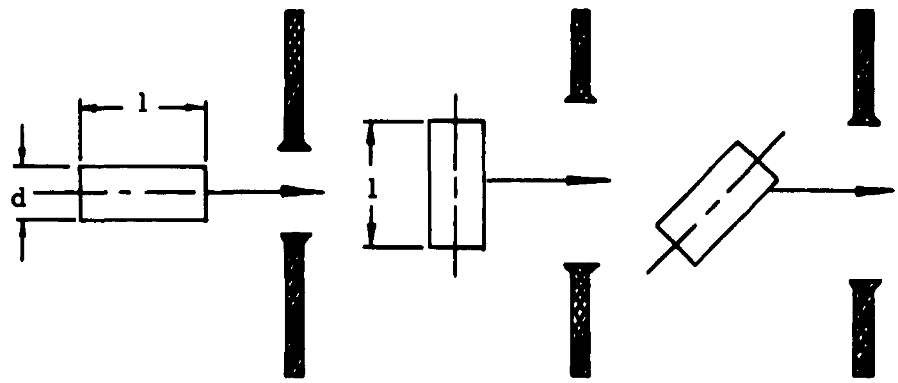
d = equivalent diameter for spherical projectile having the listed mass.

Although the range of velocities is relatively narrow (8.2 to 10.4 km/sec) all points fall below Bjork's theory for aluminum impacts on aluminum targets.

4.3 EXPLORATORY INVESTIGATIONS

4.3.1 Aluminum Projectiles, 35,000 to 39,000 ft/sec

In the special report covering the impact and penetration of thin aluminum targets by aluminum projectiles at 29,000 - 33,000 ft/sec (Reference 2) it was determined that for thin targets positioned at 90° to the impact velocity, target damage is determined primarily by the silhouette area of the impacting projectile. This was explored by the following sketch and discussion.



Cylindrical Projectiles in Various Orientations
Penetrating Thin Targets

A rod impacting with its axis coincident with the velocity and normal to the target will produce a hole whose diameter is some amount larger than the rod diameter. After the rod length exceeds a certain value, the hole diameter will be independent of the length. The same rod impacting with its axis parallel to the target will produce a hole which is longer than the rod and wider than its diameter.

For a given projectile and impact orientation, the amount by which the hole is larger than the projectile will be determined by the target thickness and the impact velocity. As the target thickness approaches zero, the hole should approach an exact profile of the projectile on the target. As the target becomes thicker, the hole (or the entrance to the impact crater) progressively becomes larger.

The above generalizations will occur because the hole boundaries are established by action of the impact-induced shock wave propagating outward from the impact zone. In an extremely thin material, the interface rarefactions will cause immediate attenuation of the shock wave. In a thicker target, this attenuation will be less rapid, hence a larger hole results.

Higher impact velocities produce stronger shock pressures, and thus larger holes. The effect of velocity will be more pronounced in thick targets, becoming negligible for extremely thin targets.

Figure 107 presents a graph with target damage plotted against projectile mass for 0.100-inch thick aluminum targets impacted by aluminum projectiles at 35,000-39,000 ft/sec. In Figure 108 the same data is plotted as a function of target damage area versus the impacting projectile area. A much smoother relationship is obtained with the latter again indicating thin target damage to be determined primarily by the impacting projectile area.

In Figure 109, the data obtained in previous investigations with aluminum projectiles impacting 0.100-inch thick aluminum targets in the 29,000-34,000 ft/sec. velocity range, target damage area is plotted against the impacting projectile area. In Figure 110 a comparison plot of target damage area versus projectile area is shown for the two velocity regimes. A higher damage curve is shown for the higher velocity range. This would be expected due to the stronger shock pressures on impact resulting from the higher impacting velocities.

As was experienced in previous investigations with thin targets, most of the holes produced by the hypervelocity impacts are circular except for the elongated holes formed by the larger projectiles having high L/D ratios.

The ratio of target hole area to projectile area is approximately 18 for the smaller projectile areas approaching 8 for the larger projectile areas. For investigations conducted in the 29,000-34,000 ft/sec. velocity range the ratio of target hole area to projectile area was nearly 15 for the smaller projectiles approaching 6 for the larger projectile areas.

4.3.2 Copper Projectiles, 22,000 - 26,000 ft/sec.

4.3.2.1 Copper Projectiles Impacted Against Thin Aluminum Plates

Figure 111 presents a graph of target hole area plotted against the impacting projectile mass for copper projectiles impacting 0.100-inch 2024-T4 aluminum targets. In Figure 112 target damage is plotted as a function of the impacting projectile area. As in previous thin target investigations the smoother relationship is obtained with the plot of target damage versus impacting projectile area.

A comparison of damage curves between Figures 109 and 112 shows that target damage for copper impacts on thin aluminum targets is approximately the same as that obtained with aluminum impacts on aluminum targets.

The ratio of projectile area to the target hole area for these investigations is approximately 15 for the smaller projectile areas and approximately 8 for the larger projectile areas.

The photographs of the target damage areas presented in Figures 78 through 84 show the tendency is toward the round hole except for the high L/D ratio cylindrical projectiles having low incidence angle with the target surface.

4.3.2.2 Copper Projectiles Impacted Against 0.500-inch Thick Copper Targets

Figure 113 shows a graph with target damage area plotted against the impacting projectile mass for soft copper targets impacted with copper projectiles at 22,600 to 26,700 ft/sec. A linear relationship is obtained from these data with target damage indicated to be proportional to the impacting projectile mass.

A comparison of the damage curves in Figures 92 and 113 show the damage obtained with copper impacts against 0.500-inch ductile copper targets to be less than that obtained with aluminum impacts against the 0.500-inch brittle 2024-T4 aluminum targets.

The photographs of the target damage areas presented in Figures 85 through 90 show the target damage to consist of round, symmetrical craters and holes.

Some of the projectiles which attained target perforation produced a "peeling" type of spallation (Figure 88, test M-761, Figure 86, test M-760). The majority of the projectiles produced the rear surface peeling and scabbing shown in Figure 90, test M-863. Figure 114 presents a sectioned view of the target plate from test M-782 showing the contours of the craters formed in the 0.500-inch copper target by these impacts along with the types and degrees of rear surface spalling.

REFERENCES

1. Squier, J., Shaped Charge Hypervelocity Fragment Projector Study - Development of Fragment Projection and Instrumentation Technique, Report APGC-TR-61-42, Air Proving Ground Center, Eglin AFB, Florida, September 1961. (Also published as Report 0377-01(15)FP, Aerojet-General Corporation, Downey, California, July 1961.

2. Kreyenhagen, K. N., et al, Impact and Penetration of 0.100-inch Aluminum Plates by Aluminum Projectiles at 29,000 - 33,000 Feet Per Second, Report No. APGC-TDR-62-40, Air Proving Ground Center, Air Force Systems Command, Eglin AFB, Florida, July 1962.

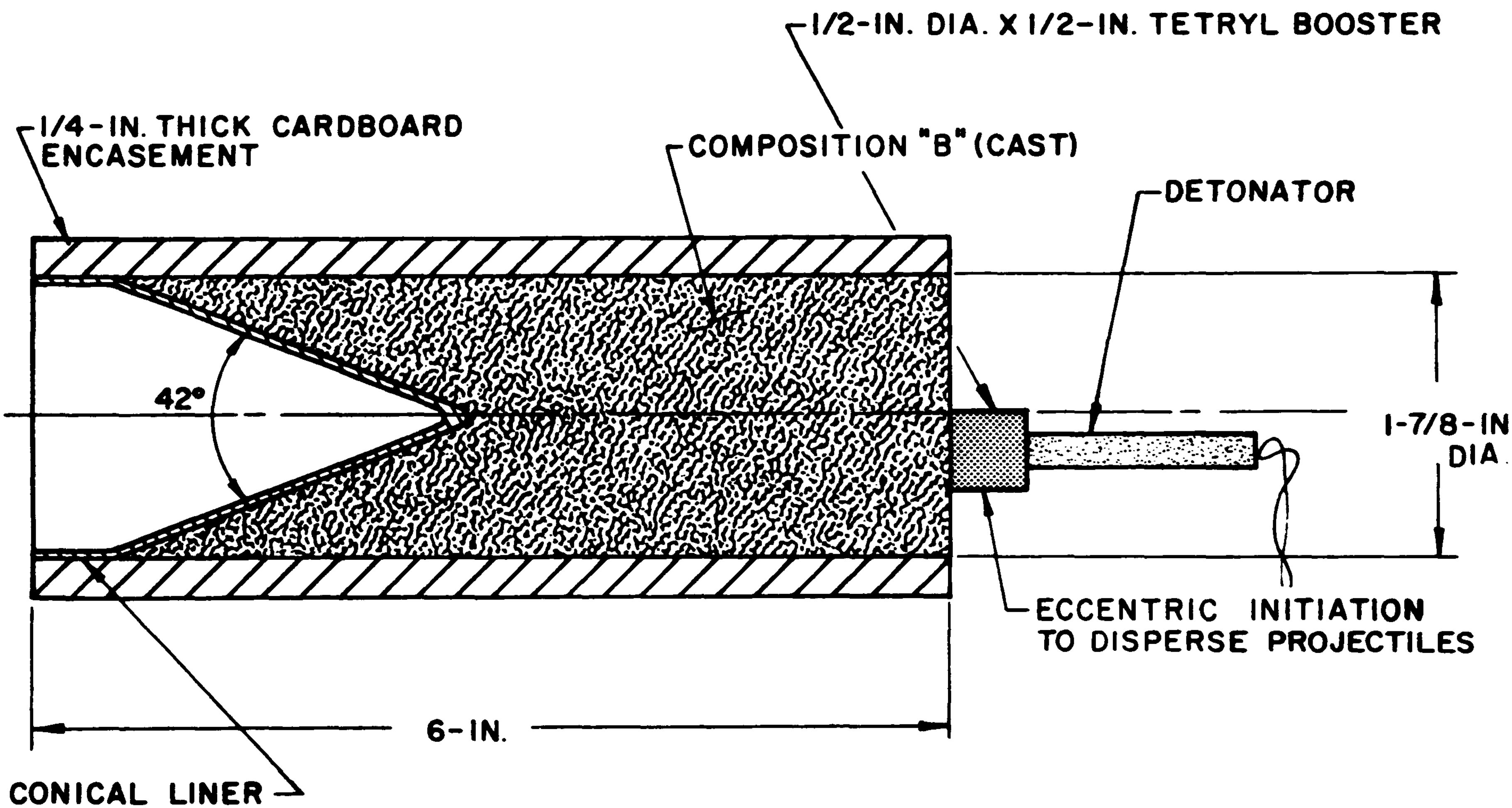


FIGURE 1 - **SHAPED CHARGE EXPLOSIVE PROJECTOR EMPLOYING 42° LINER**

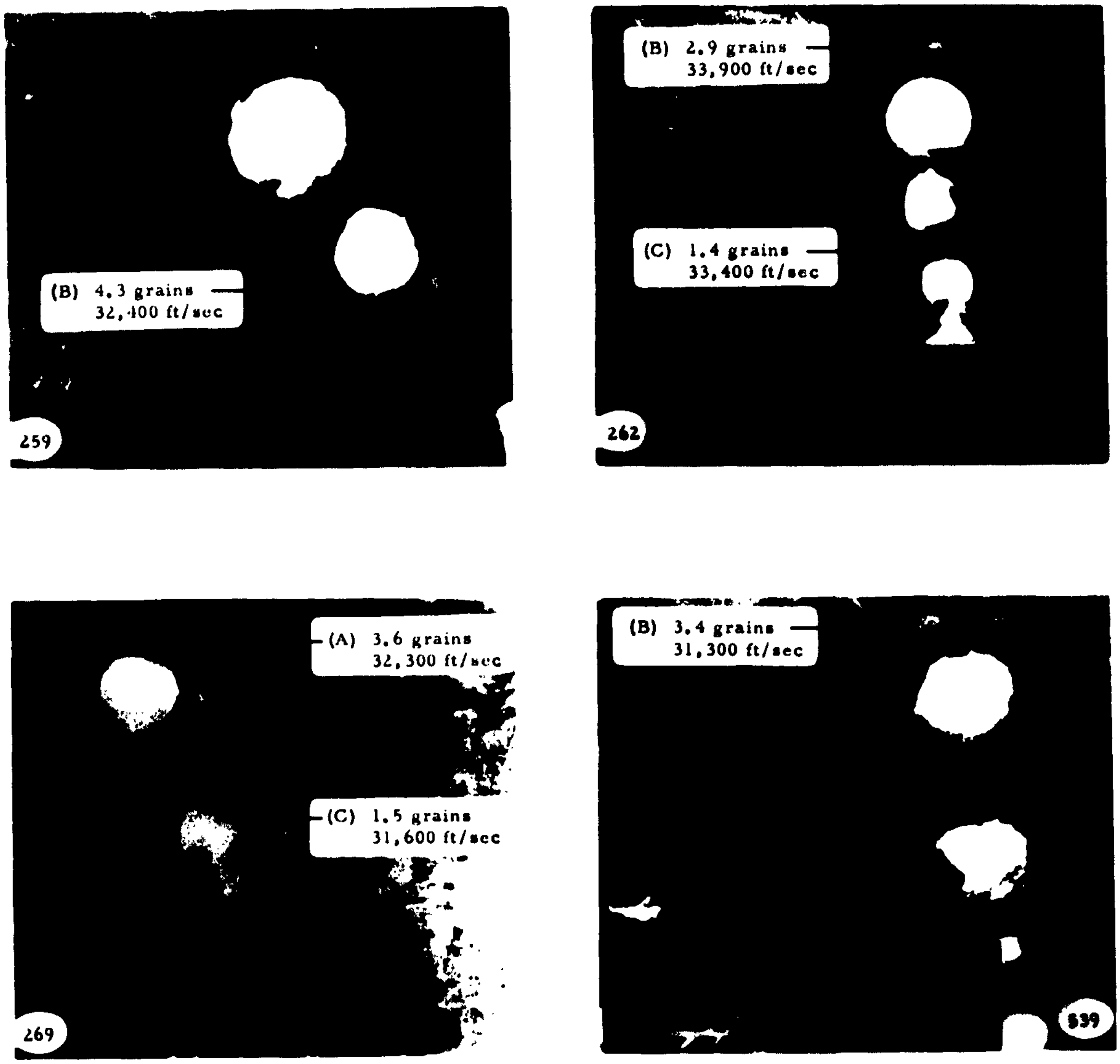


FIGURE 2. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 90° OBLIQUITY, TEST NO. M-259, M-262, M-269, and M-539.

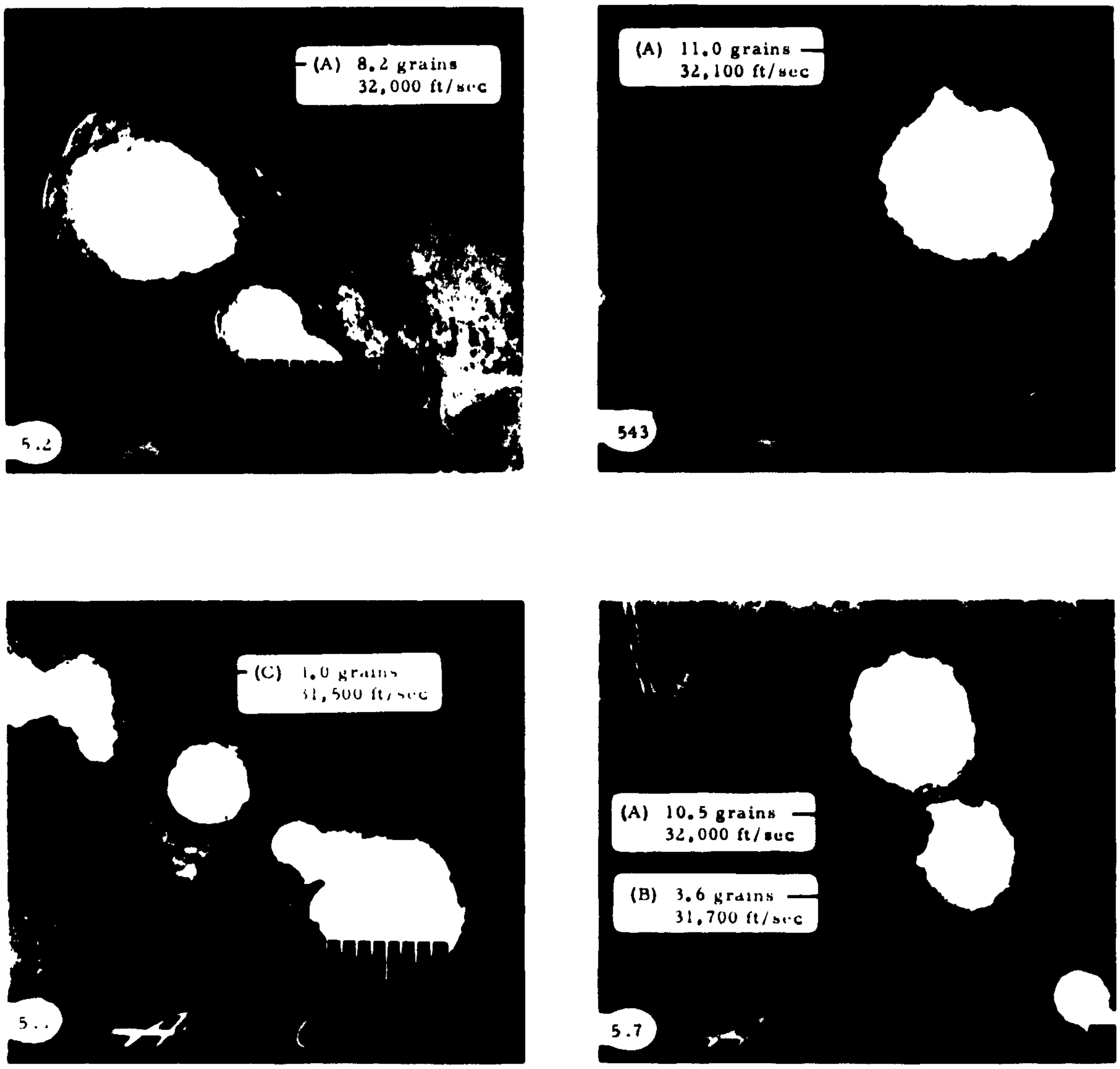
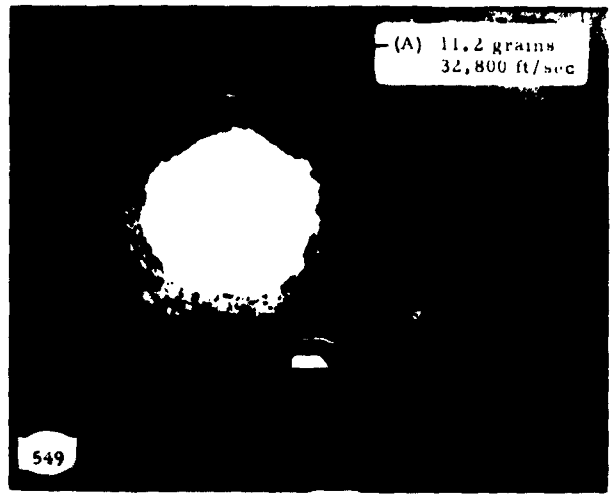


FIGURE 3. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 90° OBLIQUITY, TEST NO. M-542, M-543, M-544 and M-547.



FRONT SURFACE

BACK SURFACE

FIGURE 4. TARGET PLATE, 2024-T4 ALUMINUM, 0.375-INCH THICK, 90° OBLIQUITY, TEST NO. M-549, FRONT AND BACK SURFACE VIEW.

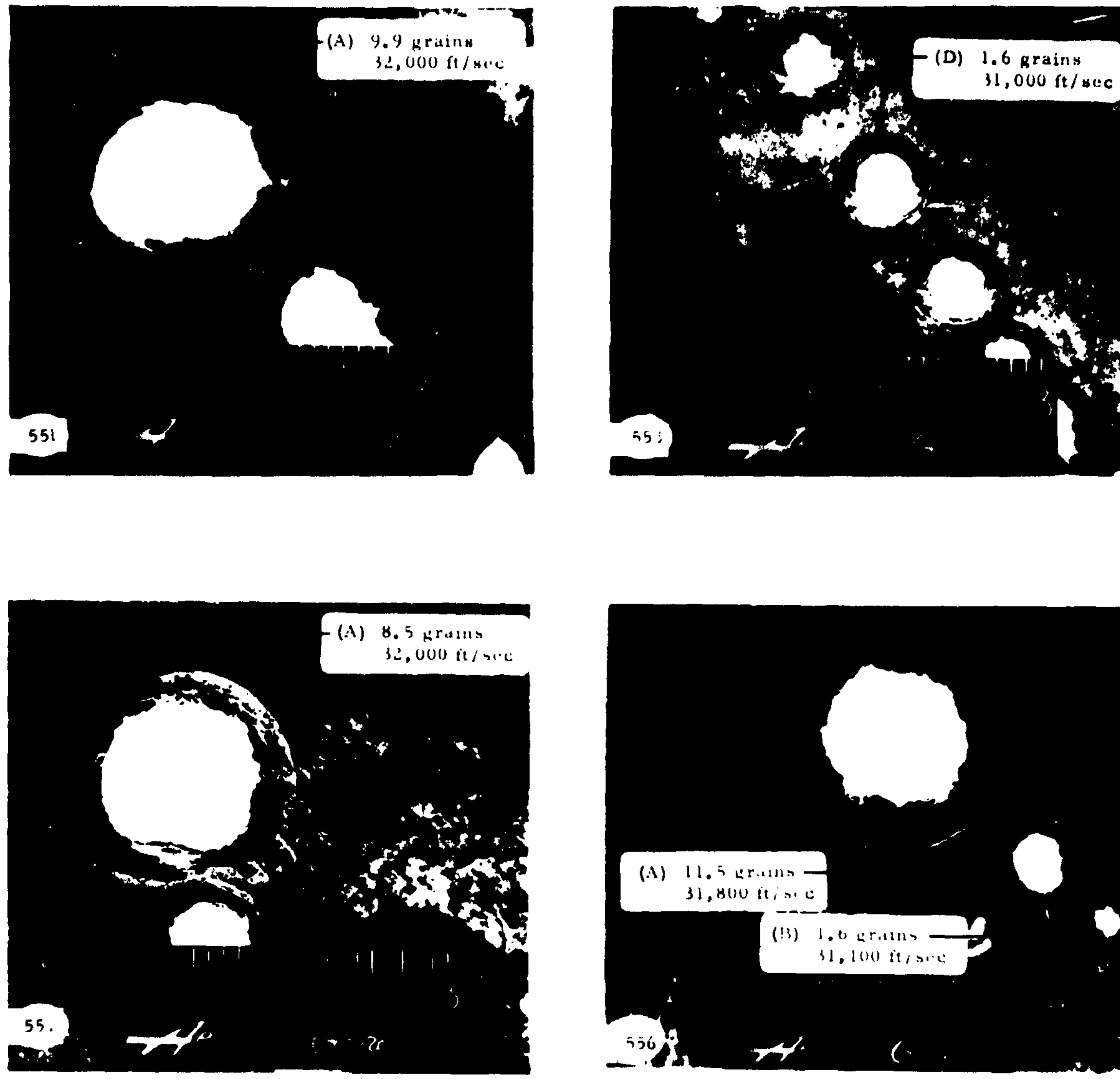


FIGURE 5. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 90° OBLIQUITY, TEST NO. M-551, M-553, M-554 and M-556.

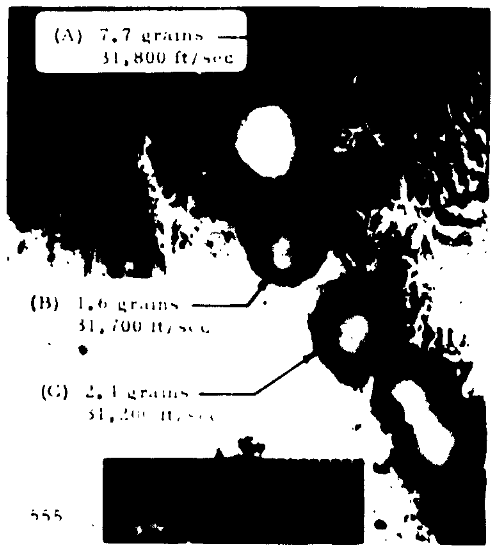


FIGURE 6. TARGET PLATE, 2024-T4 ALUMINUM, 0.375-INCH THICK, 90° OBLIQUITY, TEST NO. M-555.

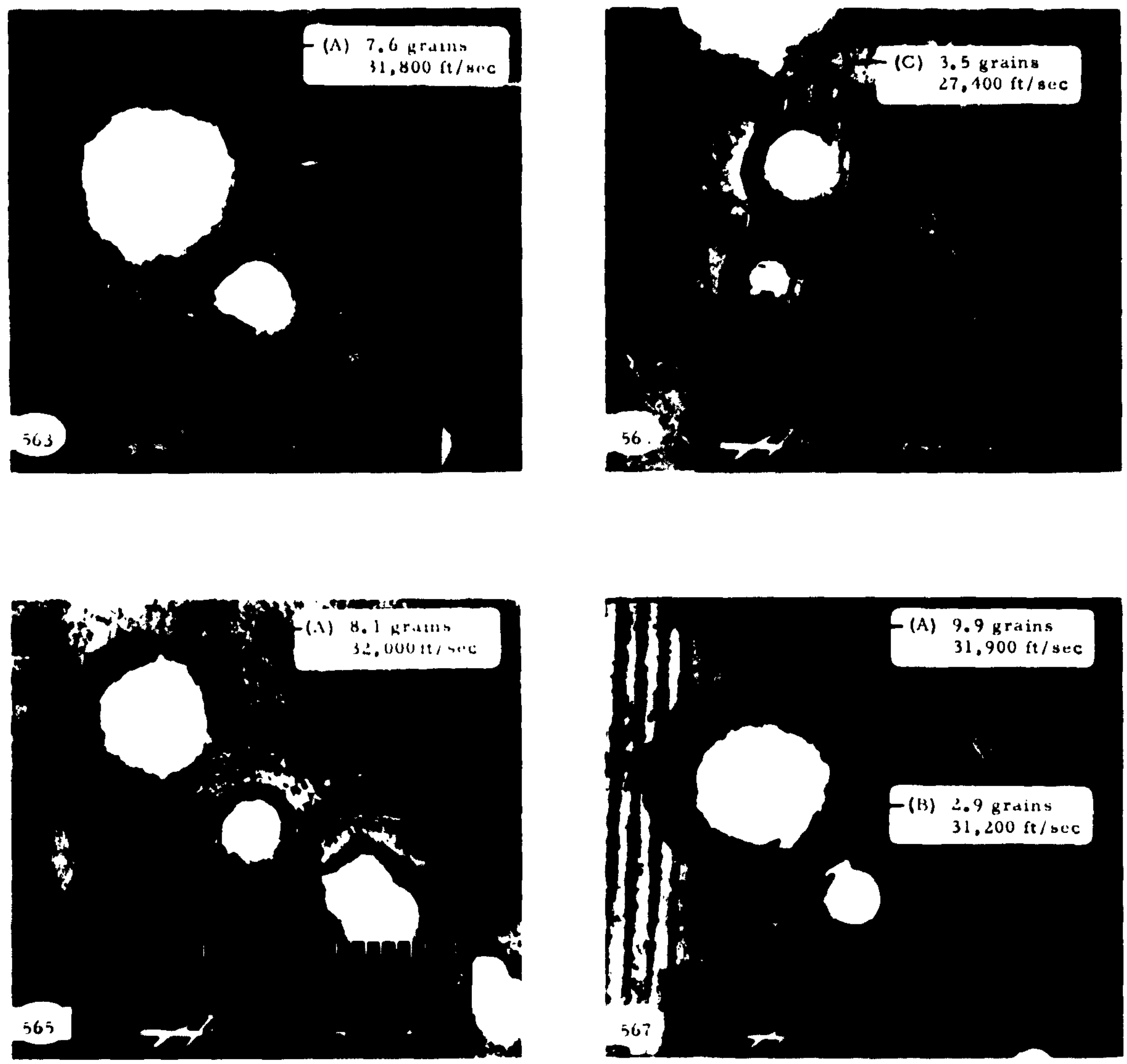


FIGURE 7. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 90° OBLIQUITY, TEST NO. M-563, M-564, M-565 and M-567.

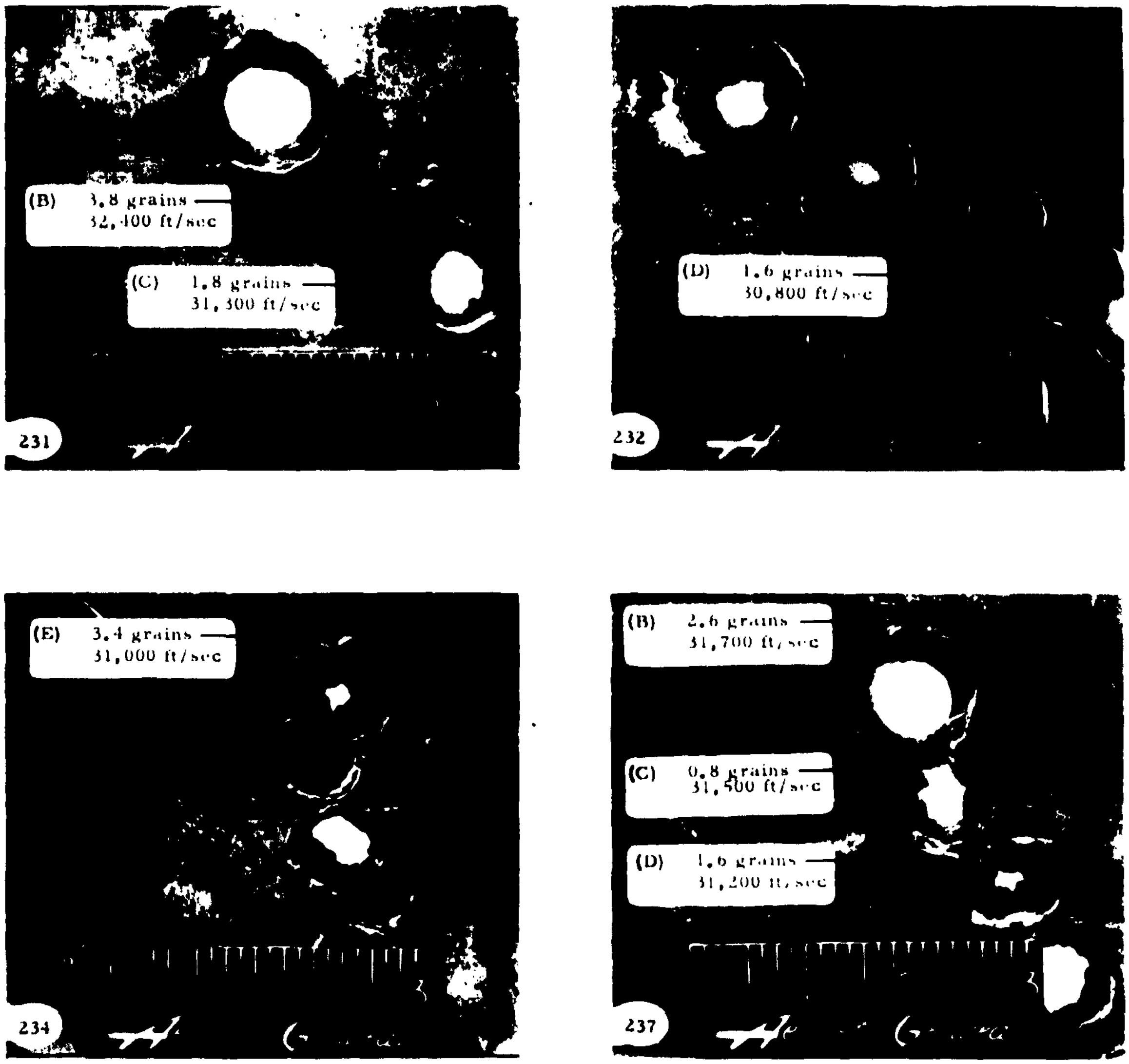


FIGURE 8. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-231, M-232, M-234 AND M-237.

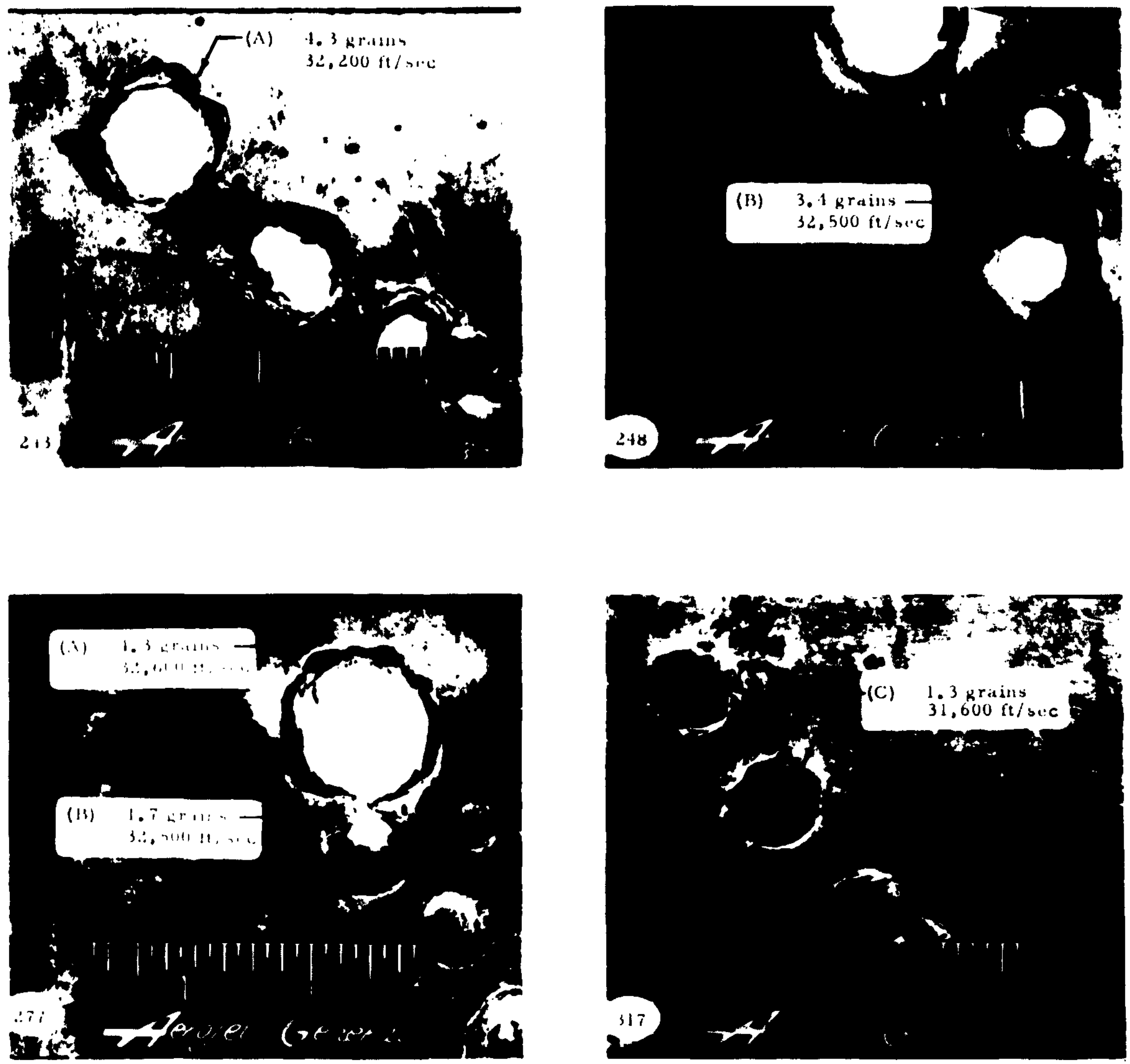
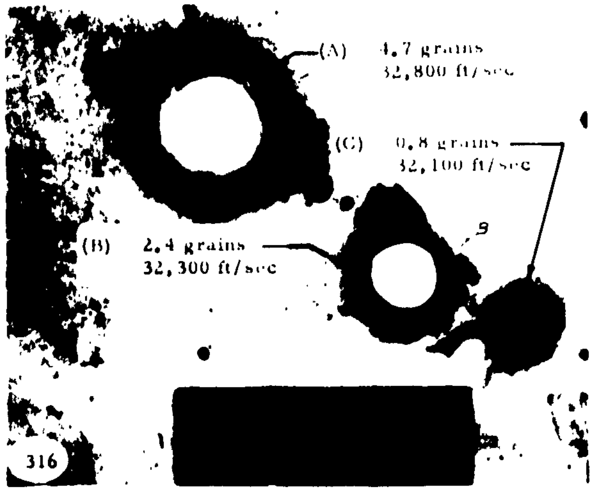
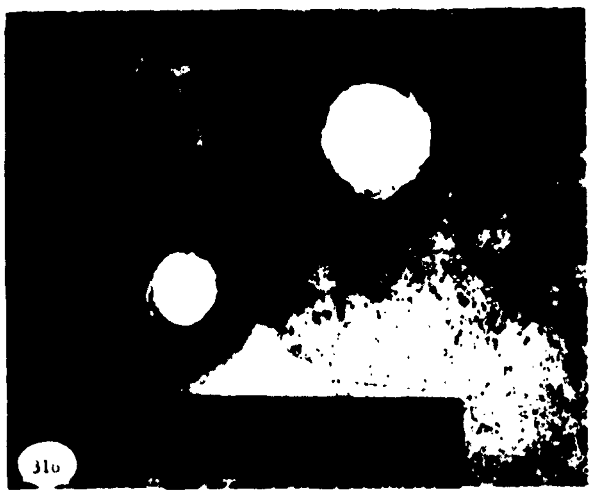


FIGURE 9. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-243, M-248, M-277, and M-317.





BACK SURFACE

FIGURE 10. TARGET PLATE, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-316, FRONT AND BACK SURFACE VIEW.

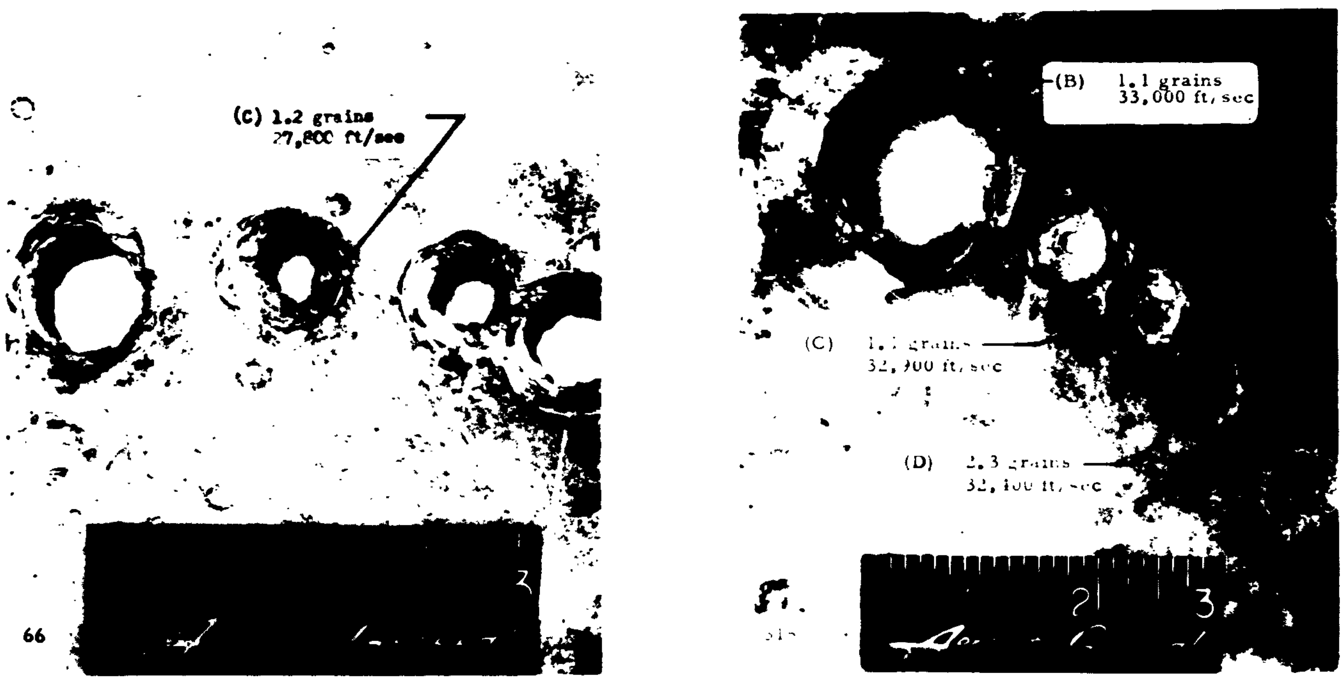


FIGURE 11. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-66 AND M-315.

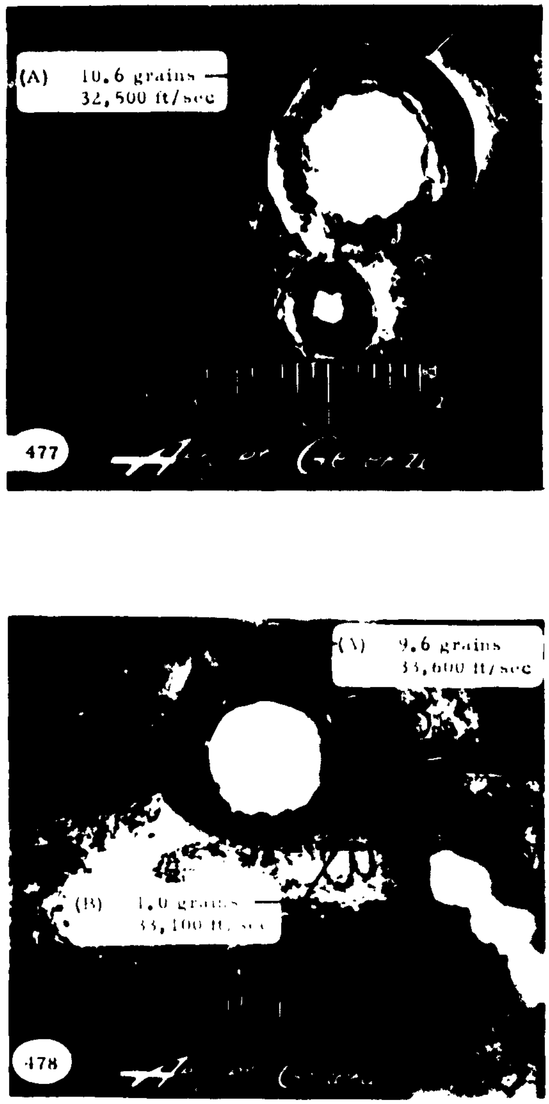


FIGURE 12. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-477 AND M-478.

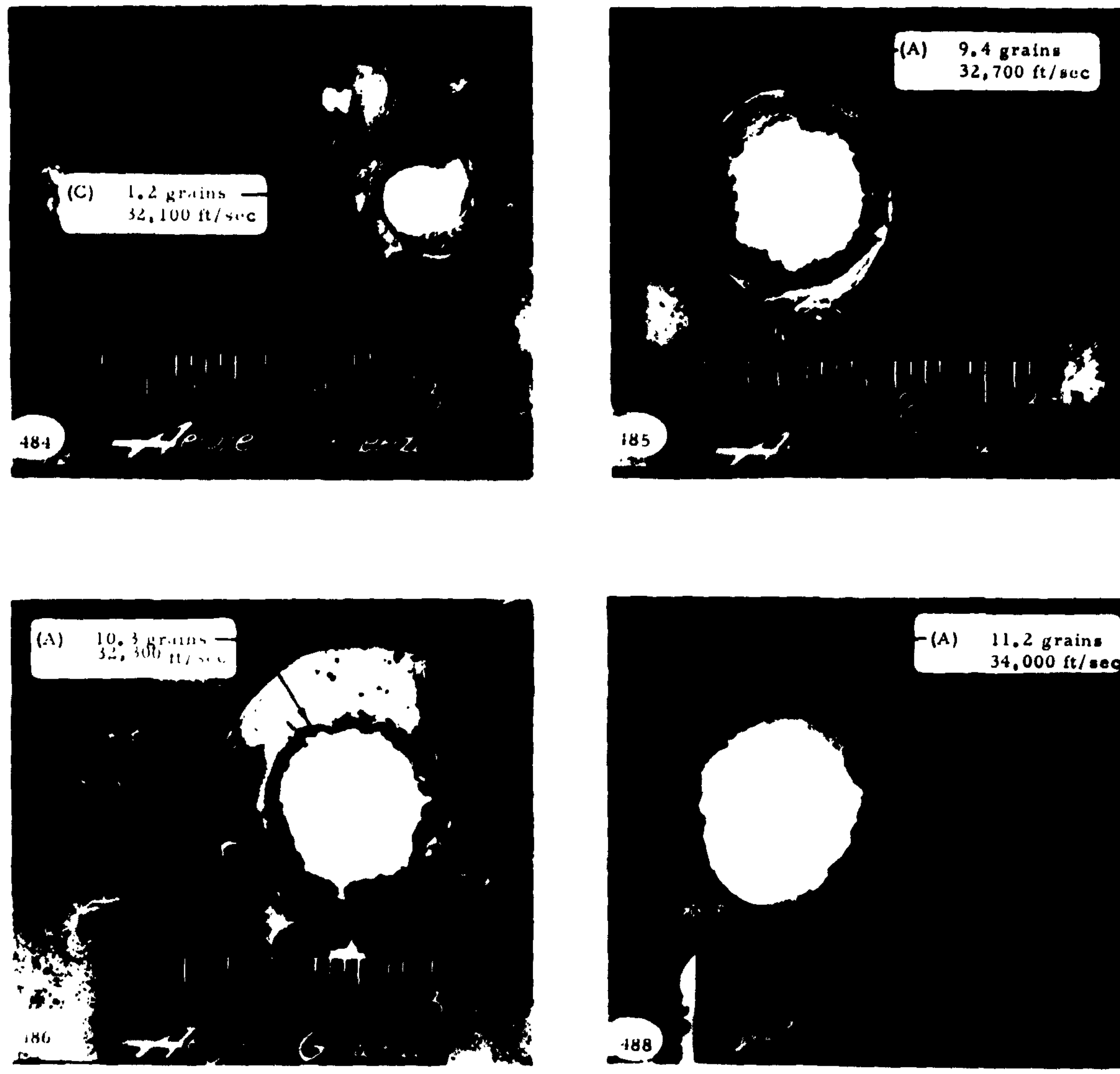


FIGURE 13. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-484, M-485, M-486 AND M-488.

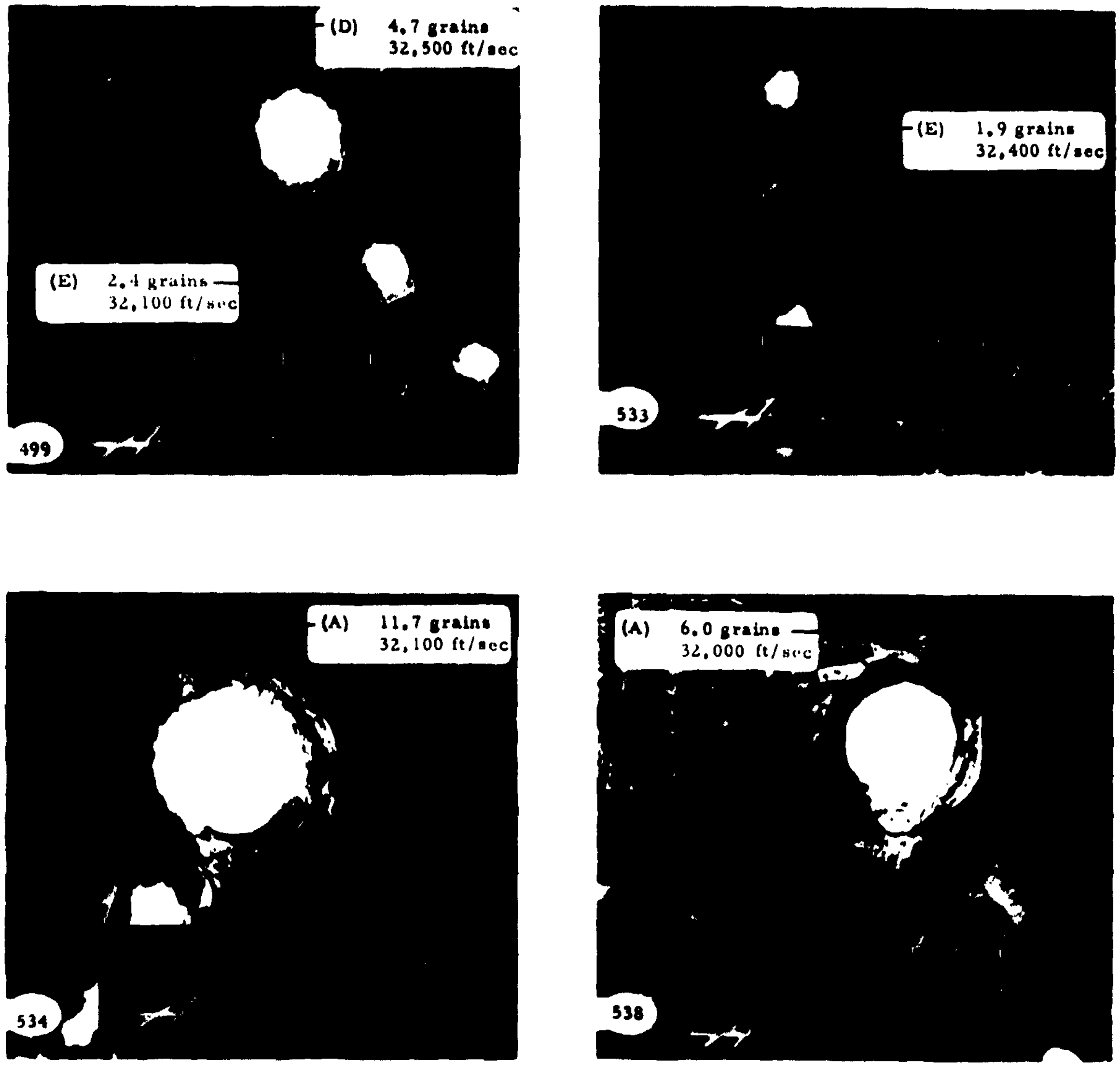
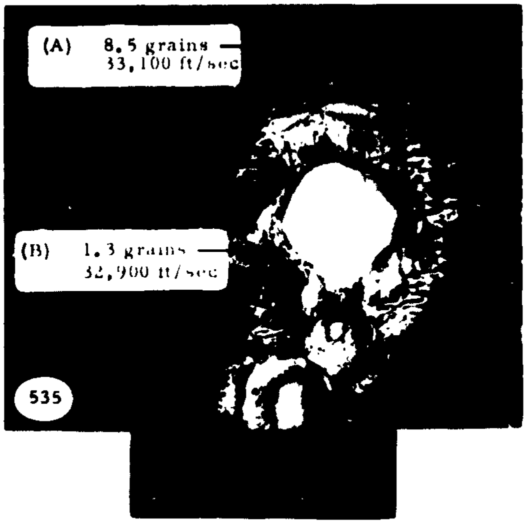


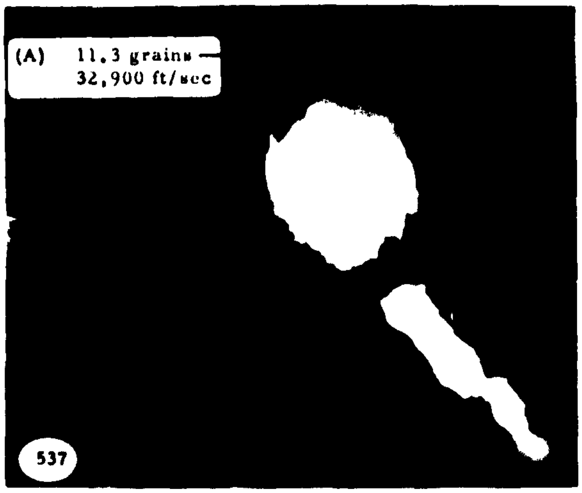
FIGURE 14. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-499, M-533, M-534 AND M-538.



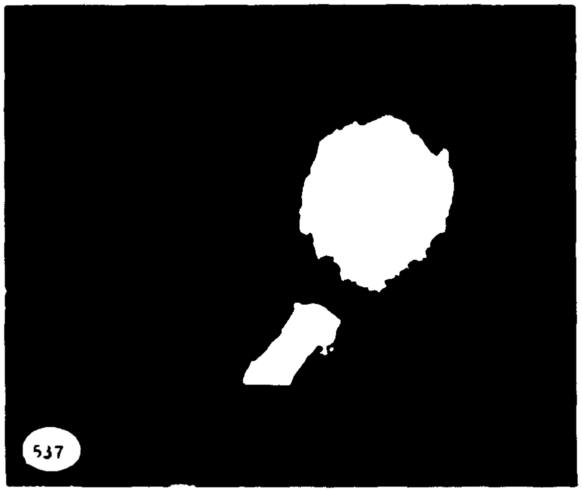
FRONT SURFACE

BACK SURFACE

FIGURE 15. TARGET PLATE, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-535, FRONT AND BACK SURFACE VIEW.



FRONT SURFACE



BACK SURFACE

FIGURE 16. TARGET PLATE, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-537, FRONT AND BACK SURFACE VIEW.

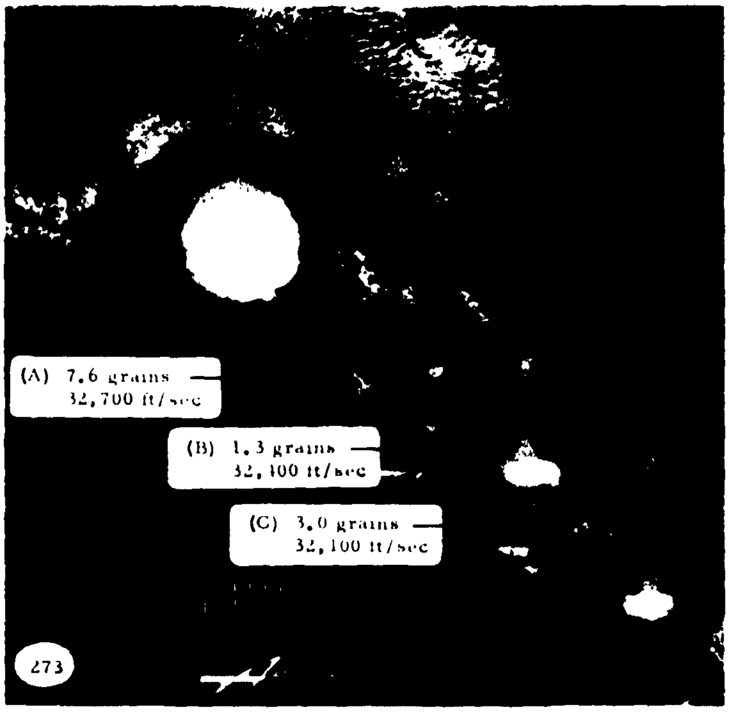
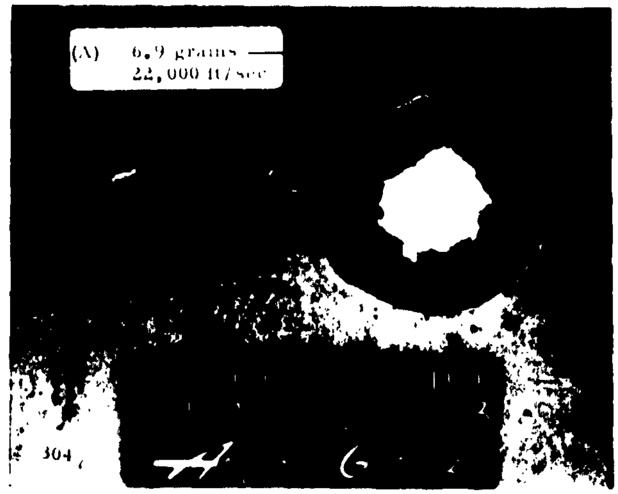
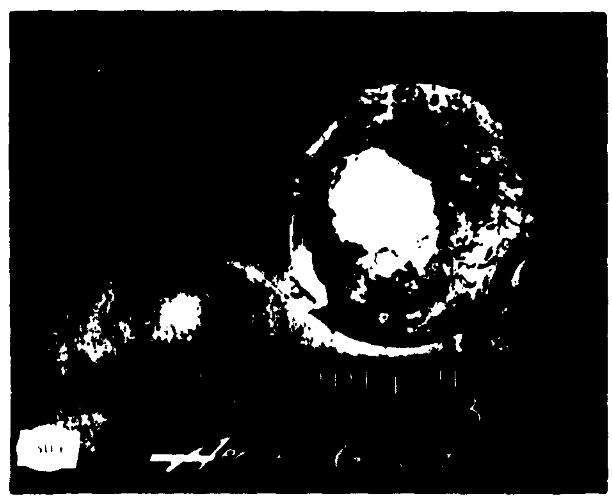


FIGURE 17. TARGET PLATE, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-273.

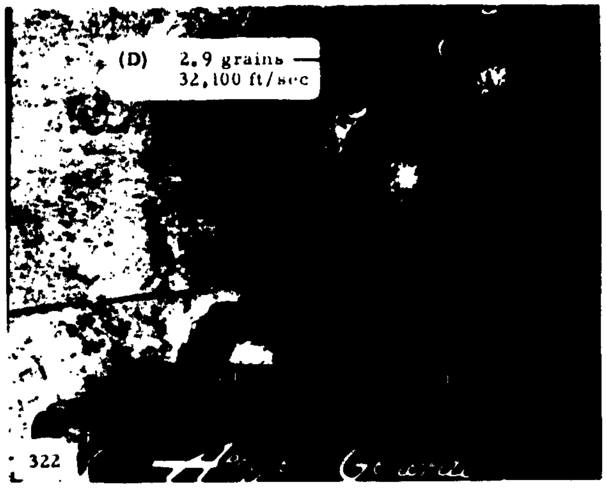


FRONT SURFACE



BACK SURFACE

FIGURE 18. TARGET PLATE, 2024-T4 ALUMINUM, 1.00-INCH THICK, 90° OBLIQUITY, TEST NO. 304, FRONT AND BACK SURFACE VIEW.



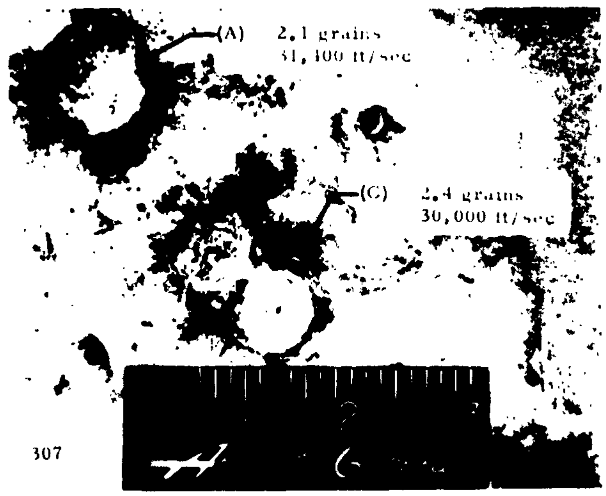


FIGURE 19. TARGET PLATES, 2024-T4 ALUMINUM, 1.00-INCH THICK, 90° OBLIQUITY, TEST NO. M-307 AND M-322.

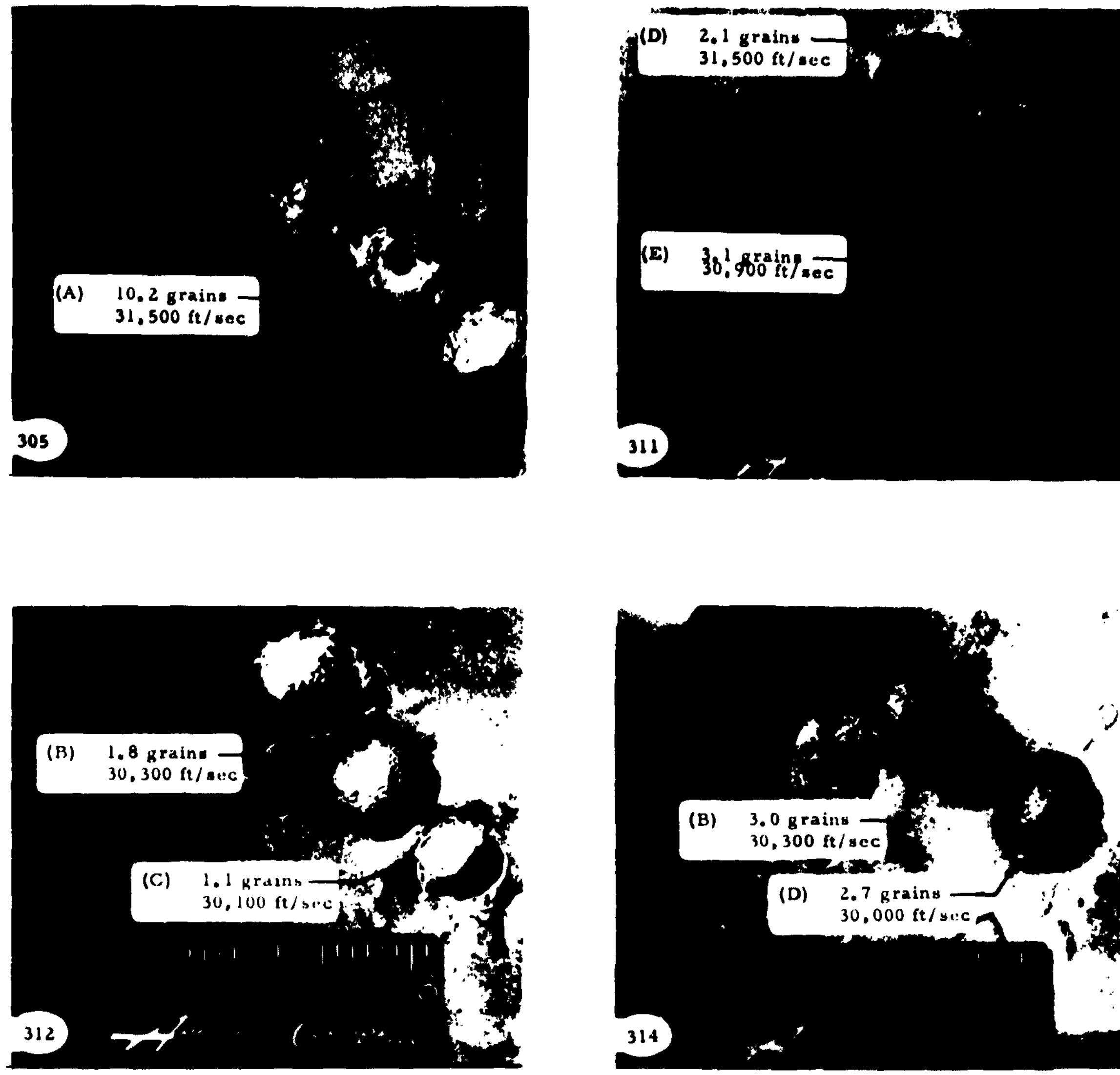
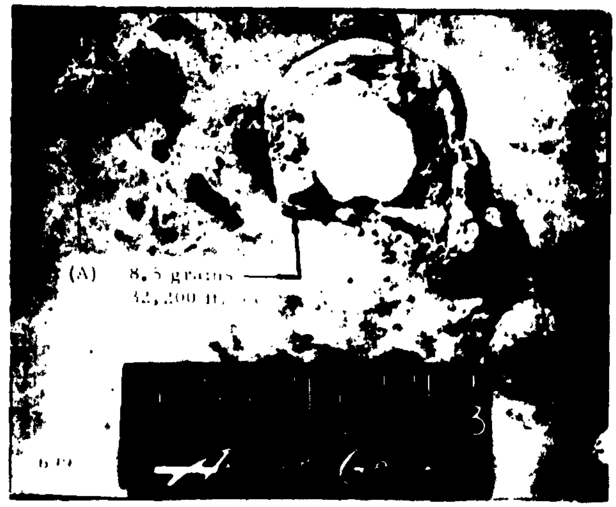


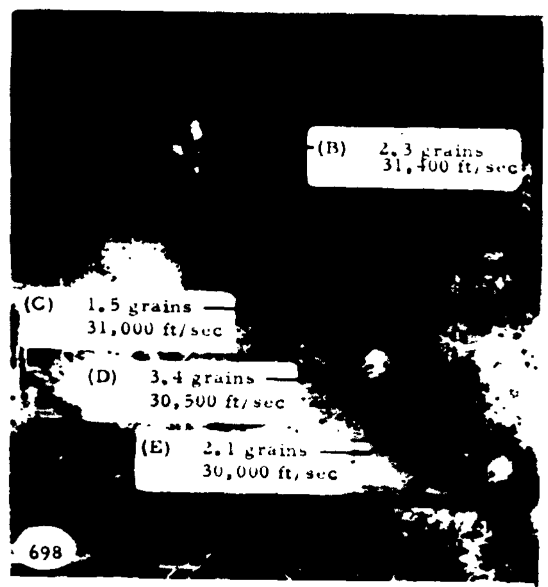
FIGURE 20. TARGET PLATES, 2024-T4 ALUMINUM, 1.00-INCH THICK, 90° OBLIQUITY, TEST NO. M-305, M-311, M-312 AND M-314.



FRONT SURFACE

BACK SURFACE

FIGURE 21. TARGET PLATE, 2024-T4 ALUMINUM, 1.00-INCH THICK, 90° OBLIQUITY, TEST NO. M-699, FRONT AND BACK SURFACE VIEW.



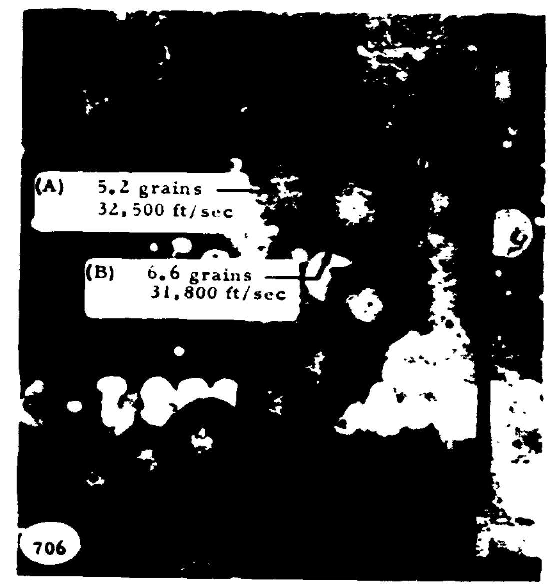


FIGURE 22. TARGET PLATES, 2024-T4 ALUMINUM, 1.00-INCH THICK, 90° OBLIQUITY, TEST NO. M-698 AND M-706.

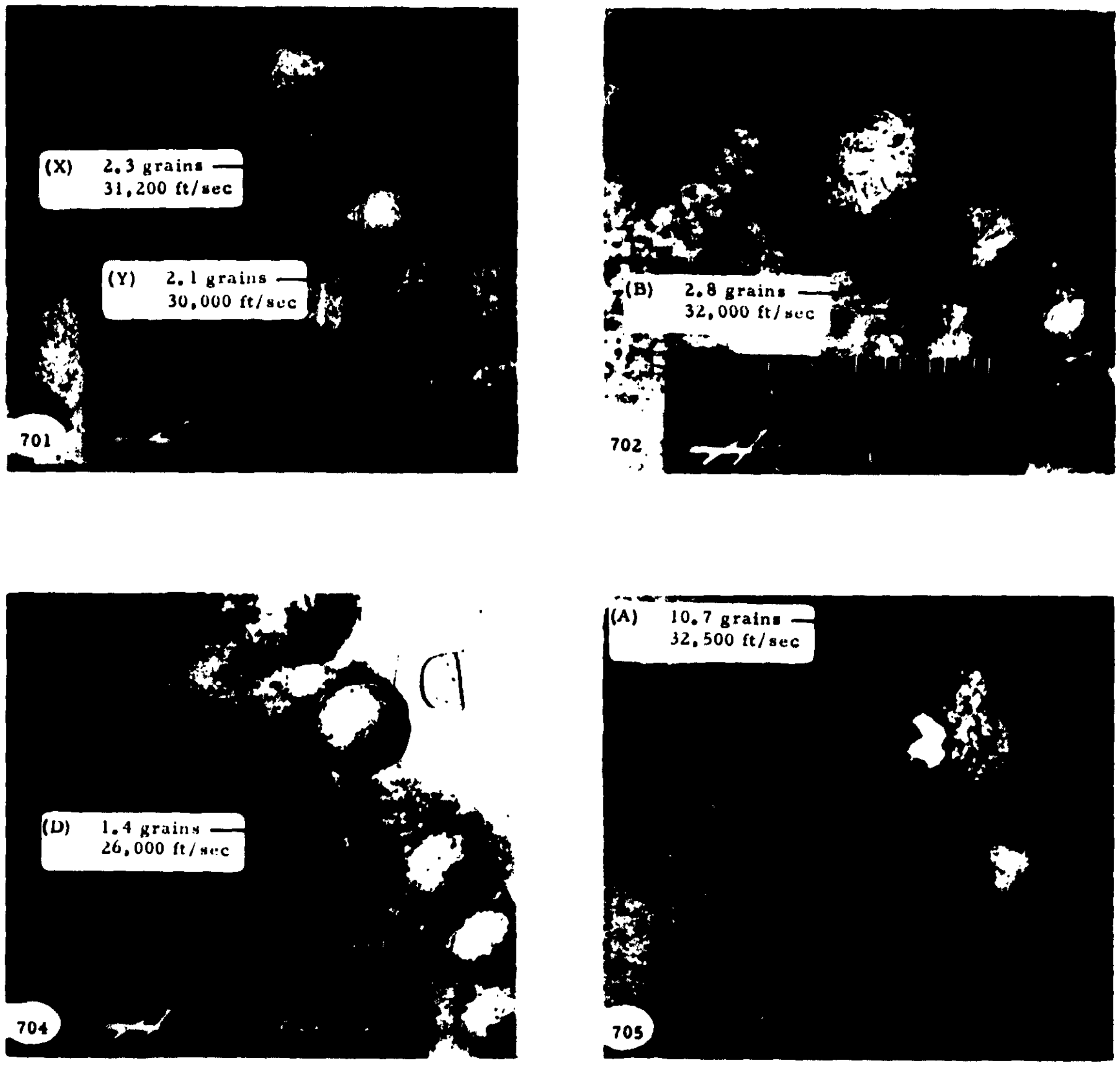


FIGURE 23. TARGET PLATES, 2024-T4 ALUMINUM, 1.00-INCH THICK, 90° OBLIQUITY, TEST NO. M-701, M-702, M-704 and M-705.

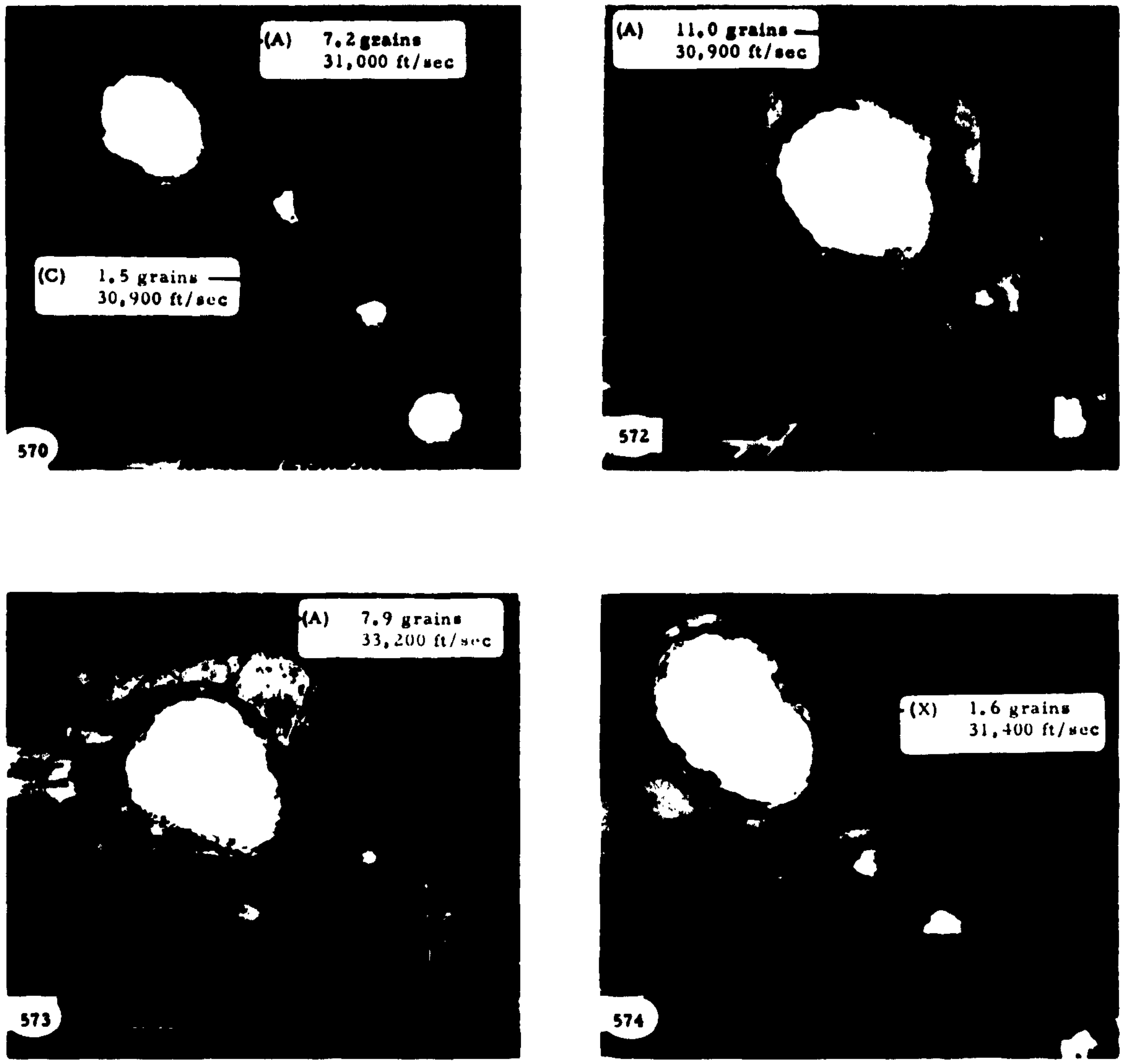


FIGURE 24. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 50° OBLIQUITY, TEST NO. M-570, M-572, M-573 AND M-574.

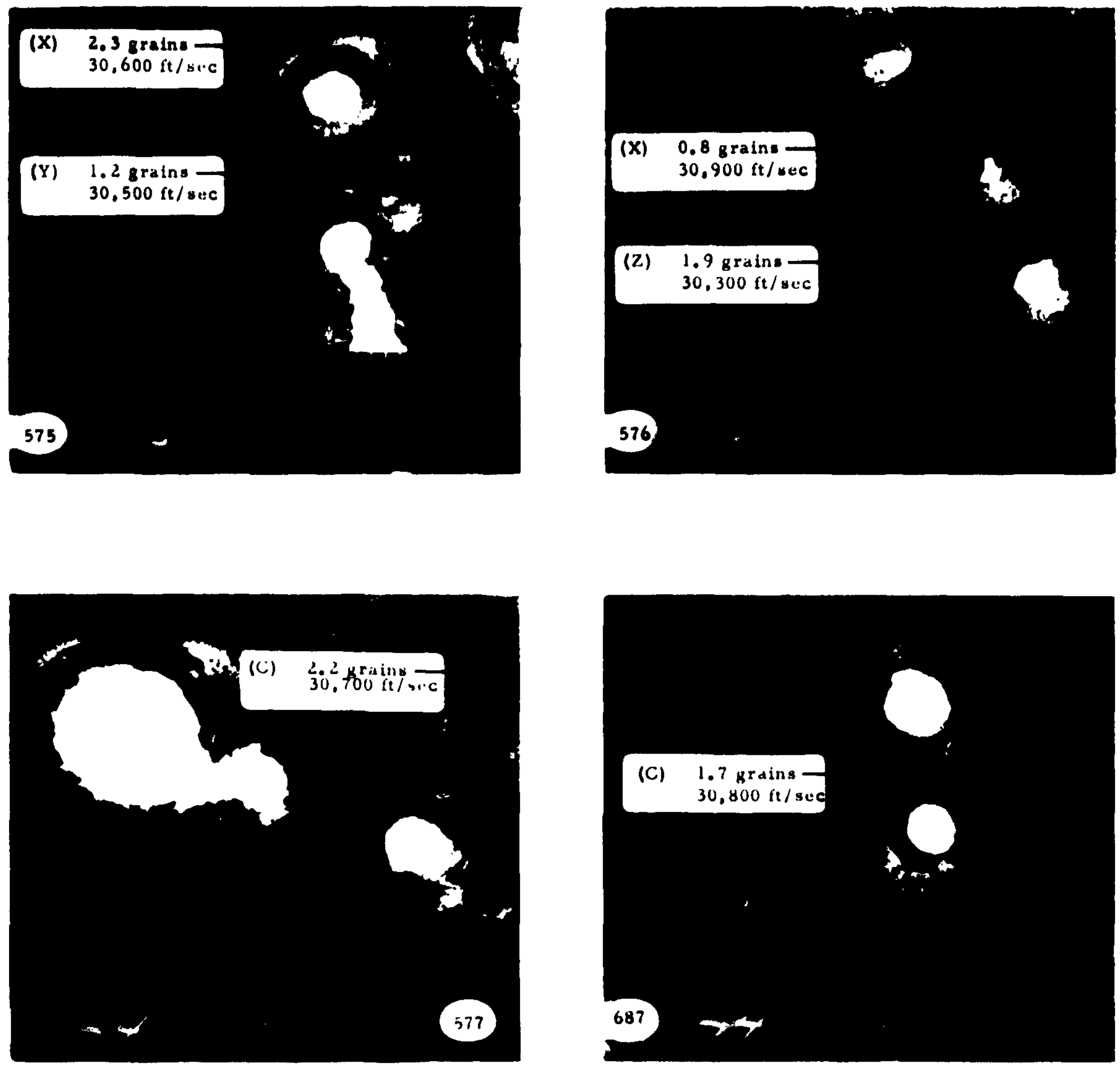


FIGURE 25. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 50° OBLIQUITY, TEST NO. M-575, M-576, M-577 AND M-687.'

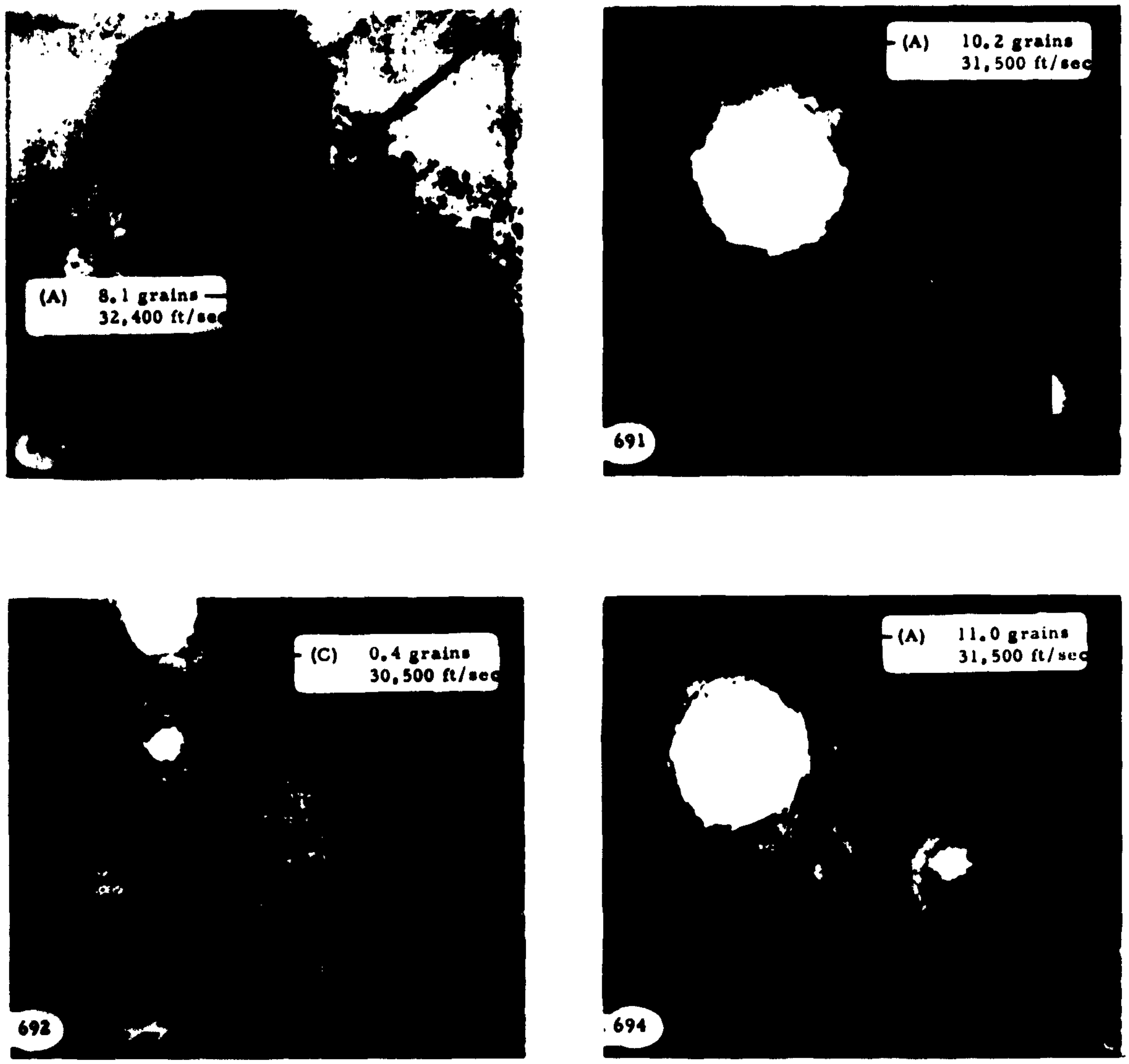
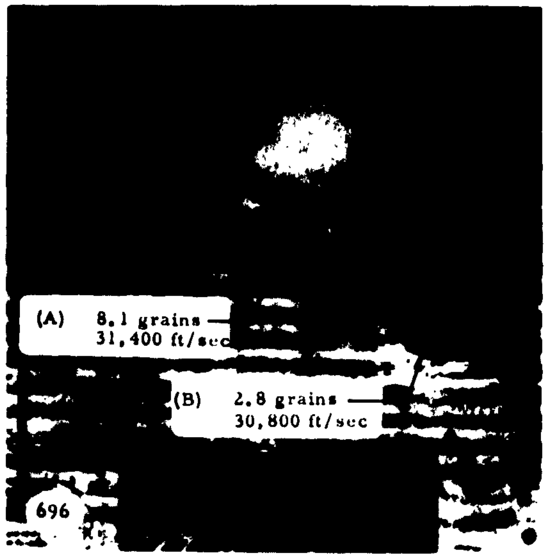


FIGURE 26. TARGET PLATES, 2024-T4
ALUMINUM, 0.375-INCH THICK,
50° OBLIQUITY, TEST NO. M-685,
M-691, M-692 and M-694.



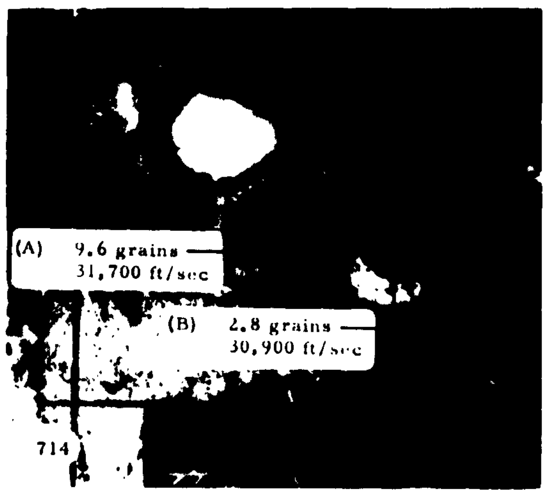
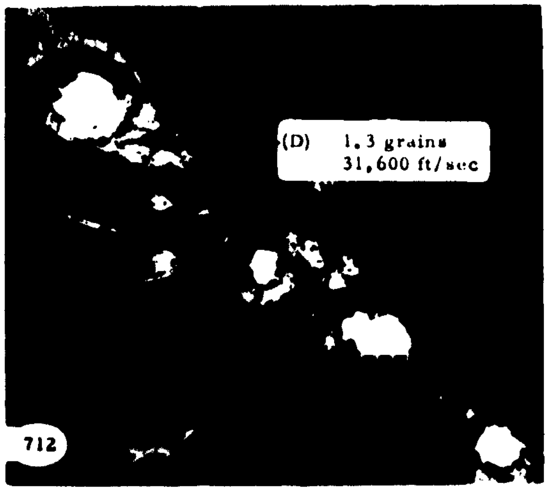


FIGURE 27. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 50° OBLIQUITY, TEST NO. M-696, AND M-714.



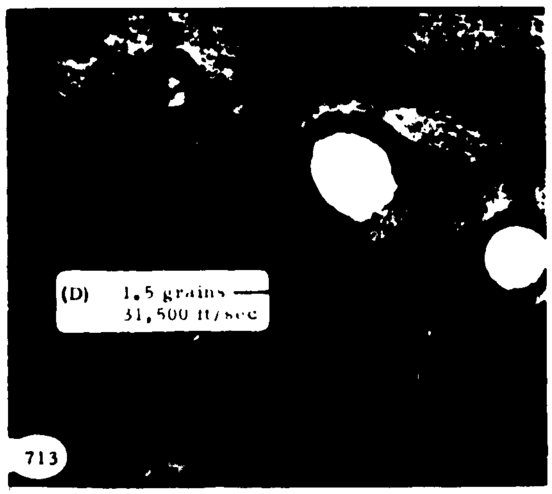


FIGURE 28. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 50° OBLIQUITY, TEST NO. M-712 AND M-713.

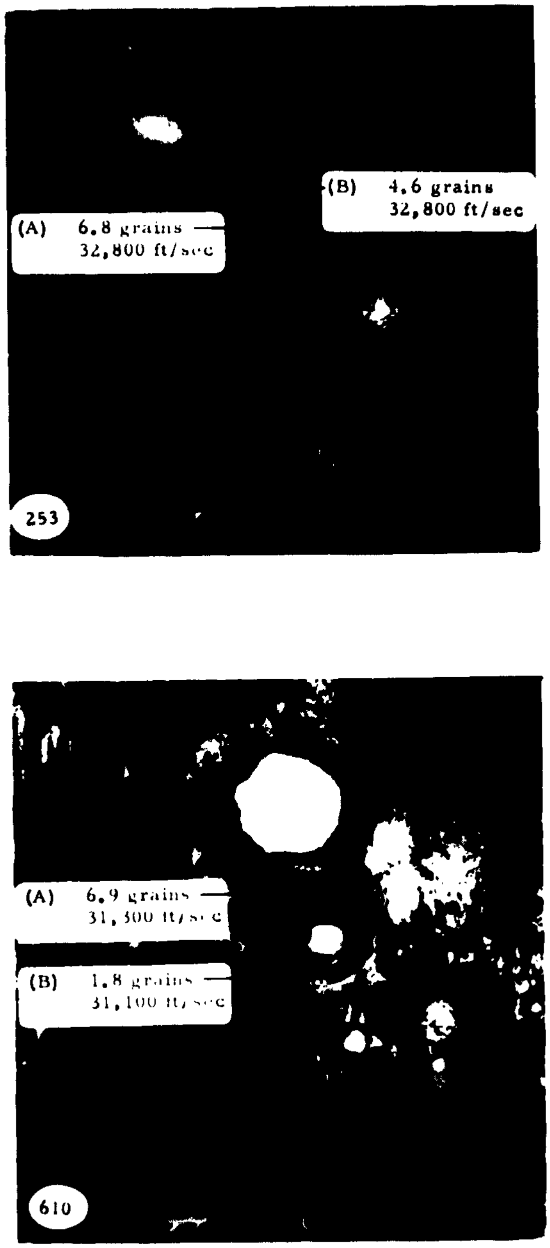


FIGURE 29. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 50° OBLIQUITY, TEST NO. M-253 AND M-610.

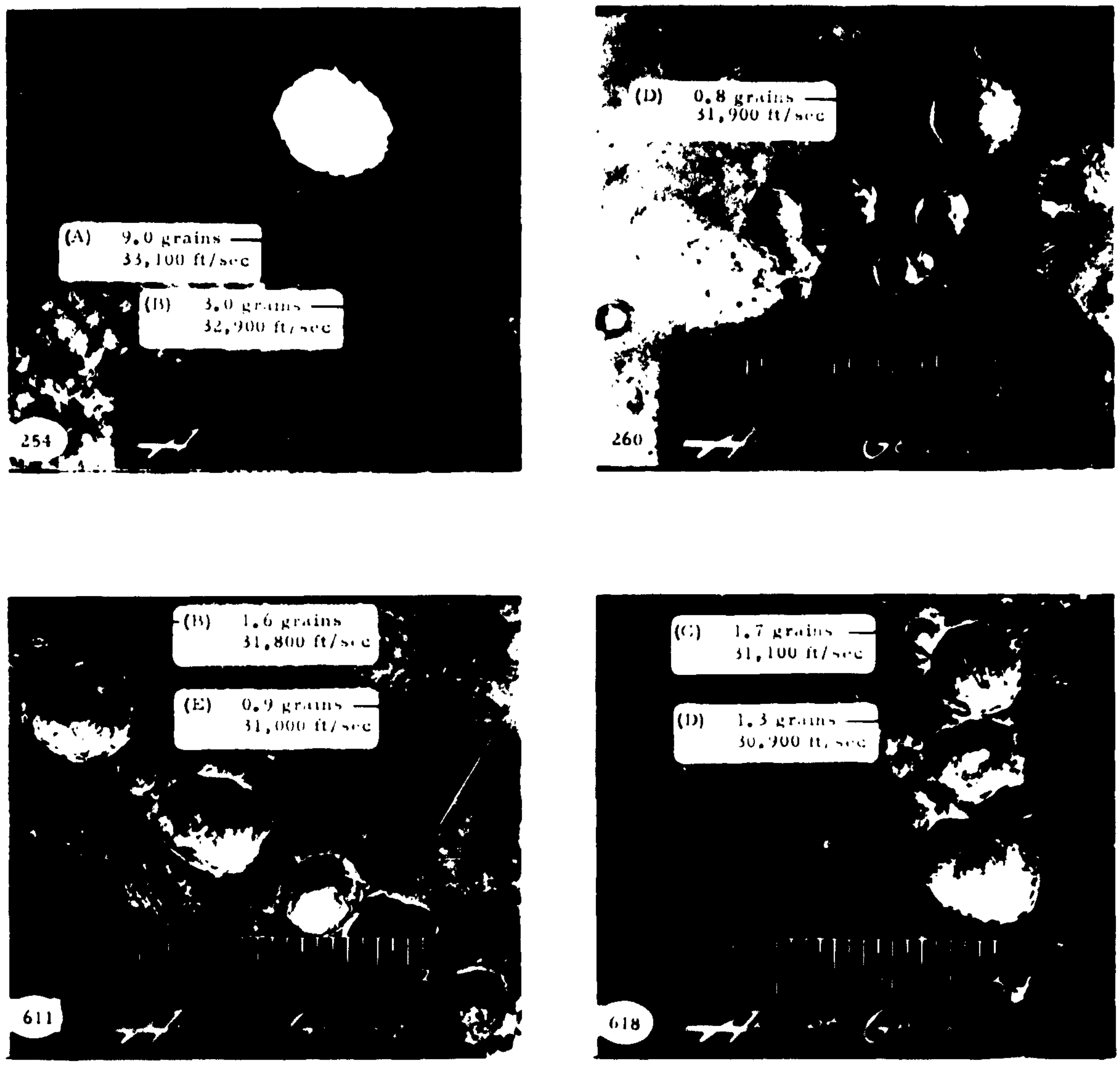


FIGURE 30. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 50° OBLIQUITY, TEST NO. M-254, M-260, M-611 AND M-618.

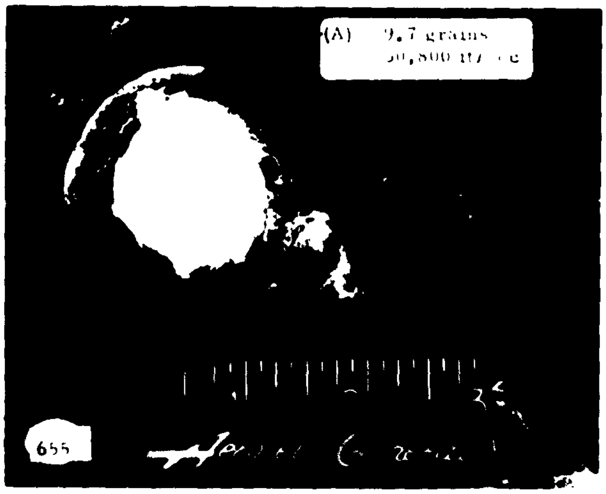


FIGURE 31. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 50° OBLIQUITY, TEST NO. M-613, AND M-655.

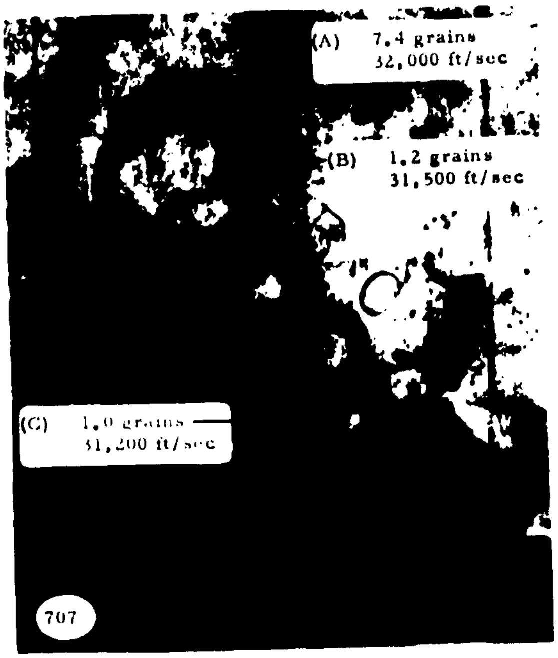


FIGURE 32. TARGET PLATE, 2024-T4 ALUMINUM, 1.00-INCH THICK, 50° OBLIQUITY, TEST NO. M-707.

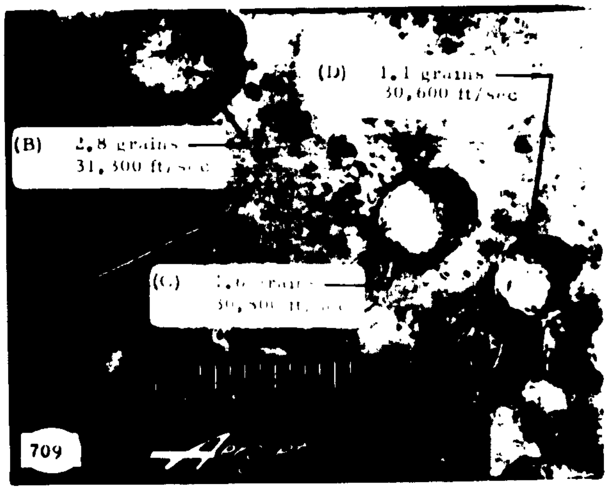
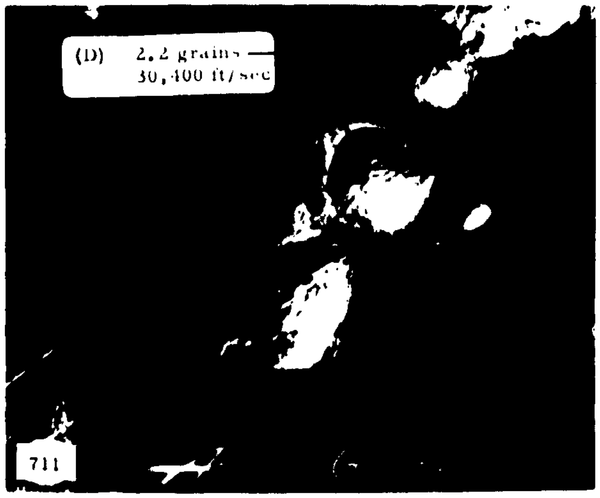


FIGURE 33. TARGET PLATE, 2024-T4 ALUMINUM, 1.00-INCH THICK, 50° OBLIQUITY, TEST NO. M-709.



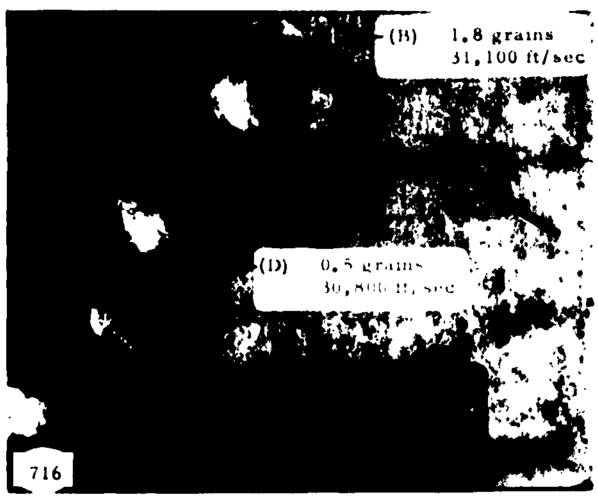


FIGURE 34. TARGET PLATES, 2024-T4 ALUMINUM, 1.00-INCH THICK, 50^{o} OBLIQUITY, TEST NO. M-711 AND M-716.

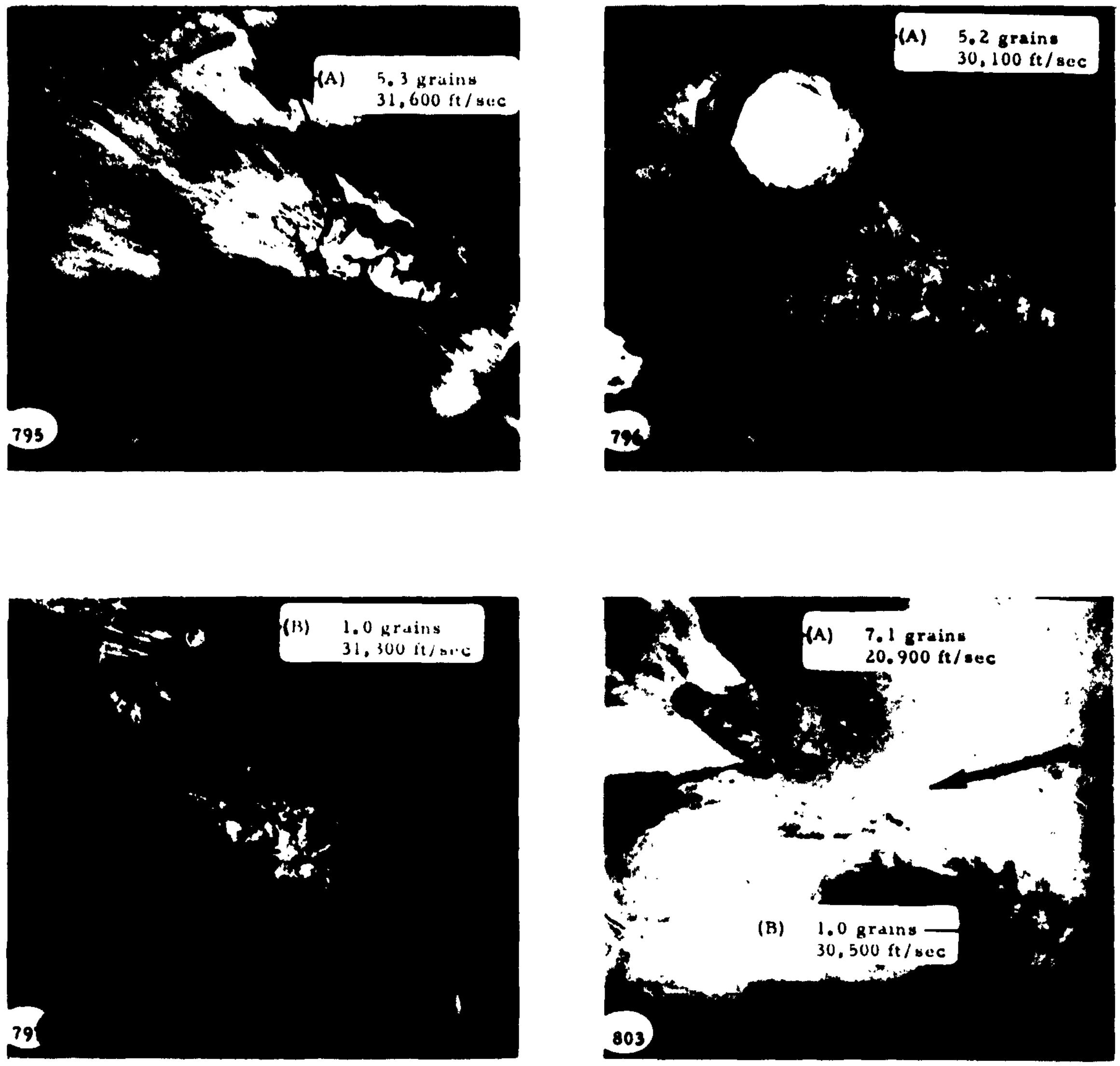


FIGURE 35. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 20° OBLIQUITY, TEST NO. M-795, M-796, M-797 AND M-803.

FIGURE 36. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 20° OBLIQUITY, TEST NO. M-806 AND M-810.

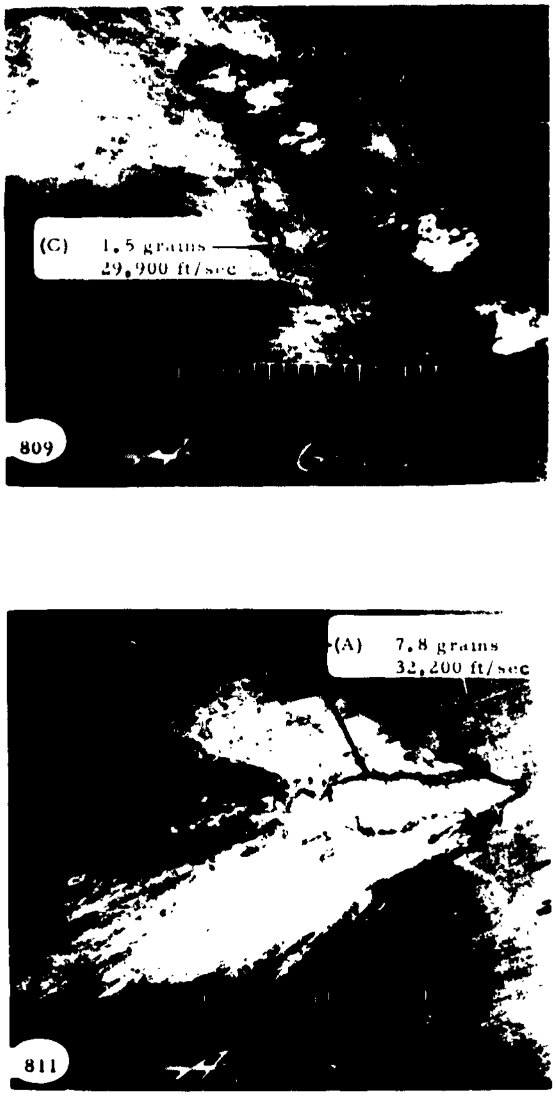


FIGURE 37. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 20° OBLIQUITY, TEST NO. M-809, AND M-811.

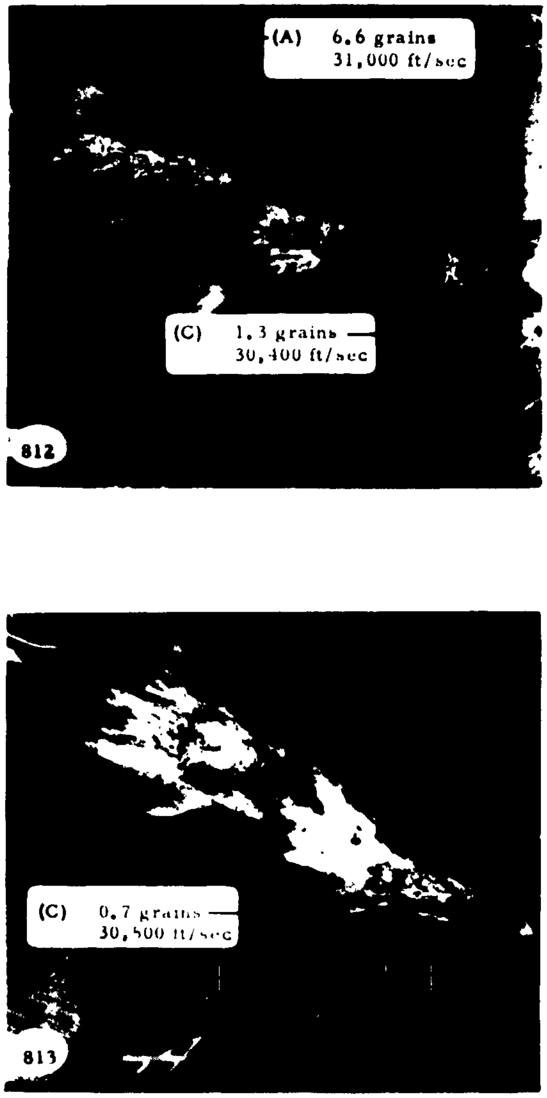


FIGURE 38. TARGET PLATES, 2024-T4 ALUMINUM, 0.375-INCH THICK, 20° OBLIQUITY, TEST NO. M-812, AND M-813.

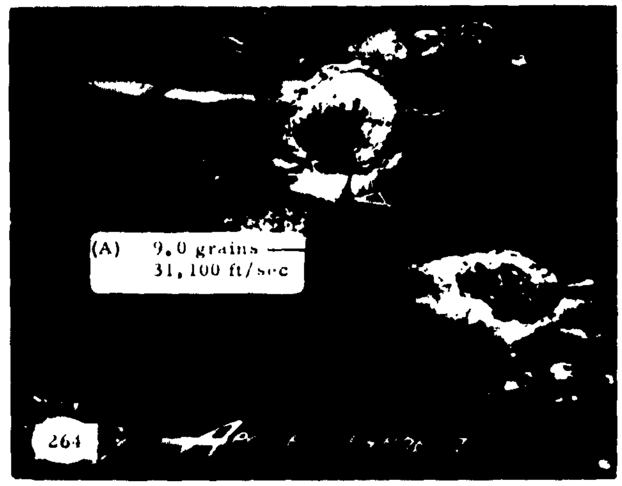


FIGURE 39. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 20° OBLIQUITY, TEST NO. M-264 AND M-267.

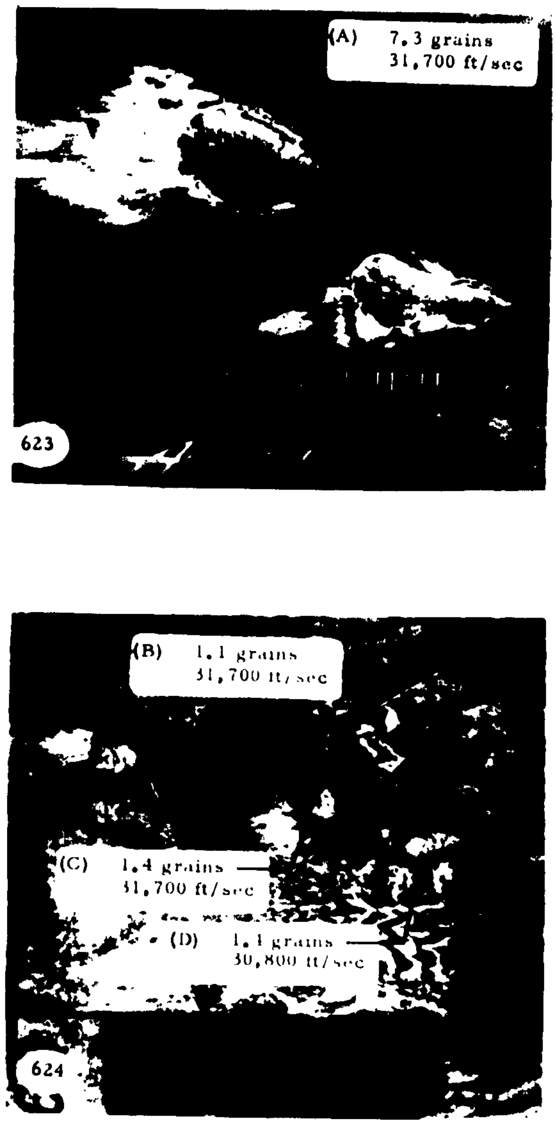


FIGURE 40. TARGET PLATES, 2024-T4 ALUMINUM, 0.500-INCH THICK, 20° OBLIQUITY, TEST NO. M-623 AND M-624.

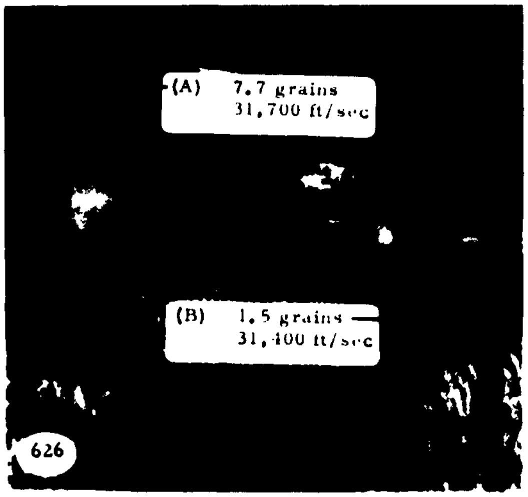


FIGURE 41. TARGET PLATE, 2024-T4 ALUMINUM, 0.500-INCH THICK, 20° OBLIQUITY, TEST NO. M-626.

FIGURE 42. SPALL ENVELOPE BEHIND 0.500-INCH ALUMINUM TARGET, APPROXIMATELY 15 MICROSEC AFTER 30,000 FT/SEC IMPACT OF ALUMINUM PROJECTILE

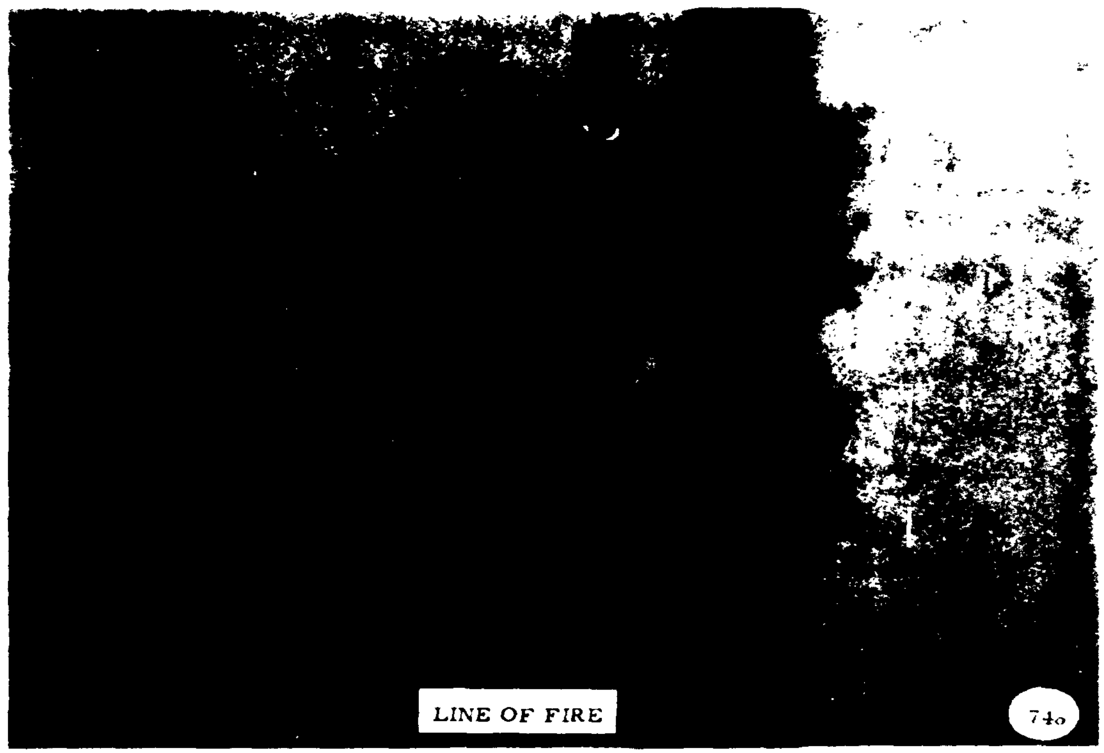
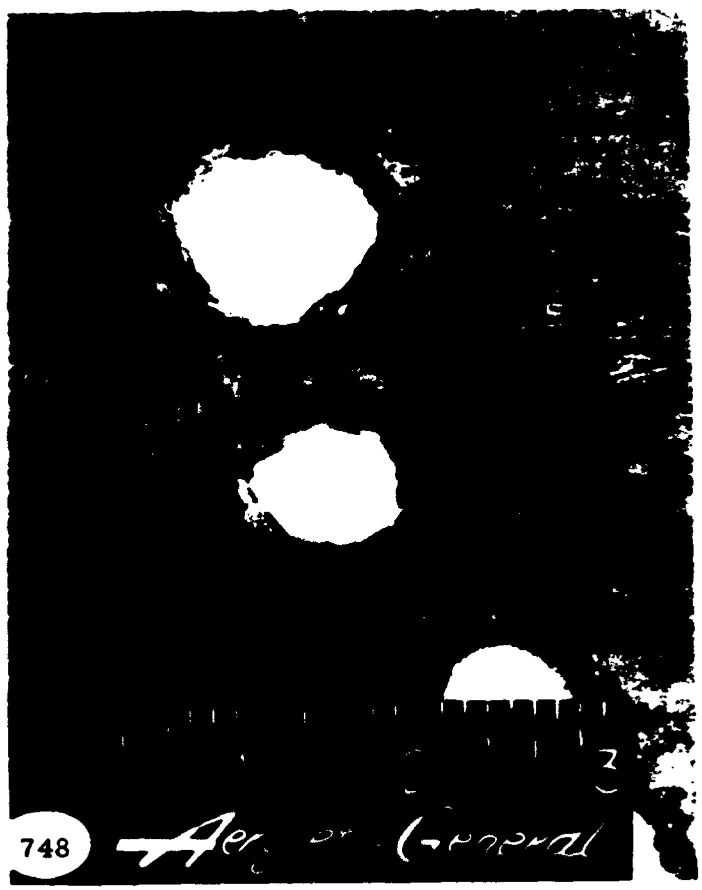


FIGURE 43. RESIDUAL/SPALL ENVELOPE BEHIND 0.500-INCH ALUMINUM TARGET, APPROXIMATELY 13 MICROSEC AFTER 30,000 FT/SEC IMPACT OF ALUMINUM PROJECTILE



FRONT SURFACE

BACK SURFACE

FIGURE 44. FRONT AND BACK SURFACE OF TARGET PLATE FROM TEST NO. 748, 2024-T4 ALUMINUM, 0.375-INCH THICK, 90° OBLIQUITY

FIGURE 45. SPALL ENVELOPE BEHIND 0.500-INCH ALUMINUM TARGET, APPROXIMATELY 5 MICROSEC AFTER 32,000 FT/SEC IMPACT BY ALUMINUM PROJECTILE

FRONT SURFACE

BACK SURFACE

FIGURE 46. FRONT AND BACK SURFACE OF TARGET PLATE FROM TEST NO. 769, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY

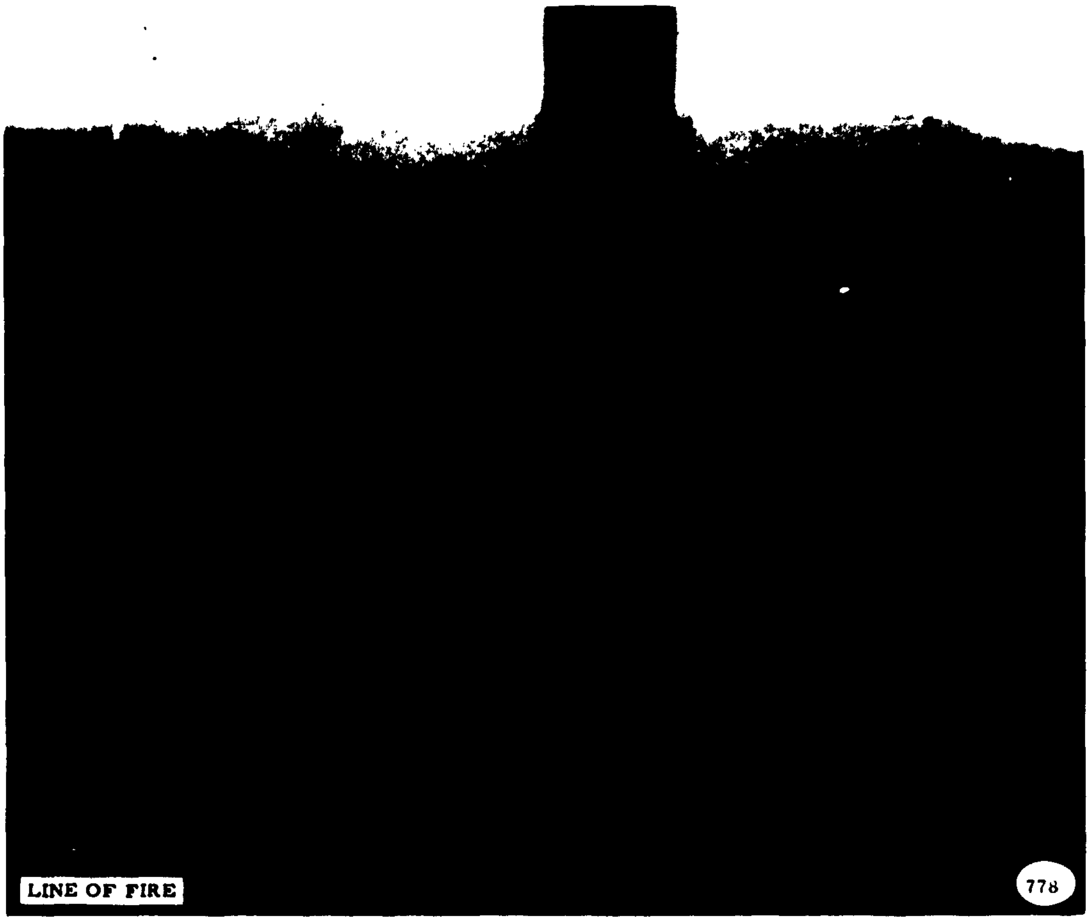


FIGURE 47. RESIDUAL/SPALL ENVELOPE BEHIND 0.500-INCH ALUMINUM TARGET, APPROXIMATELY 16 MICROSEC AFTER 31,000 FT/SEC IMPACT BY ALUMINUM PROJECTILE

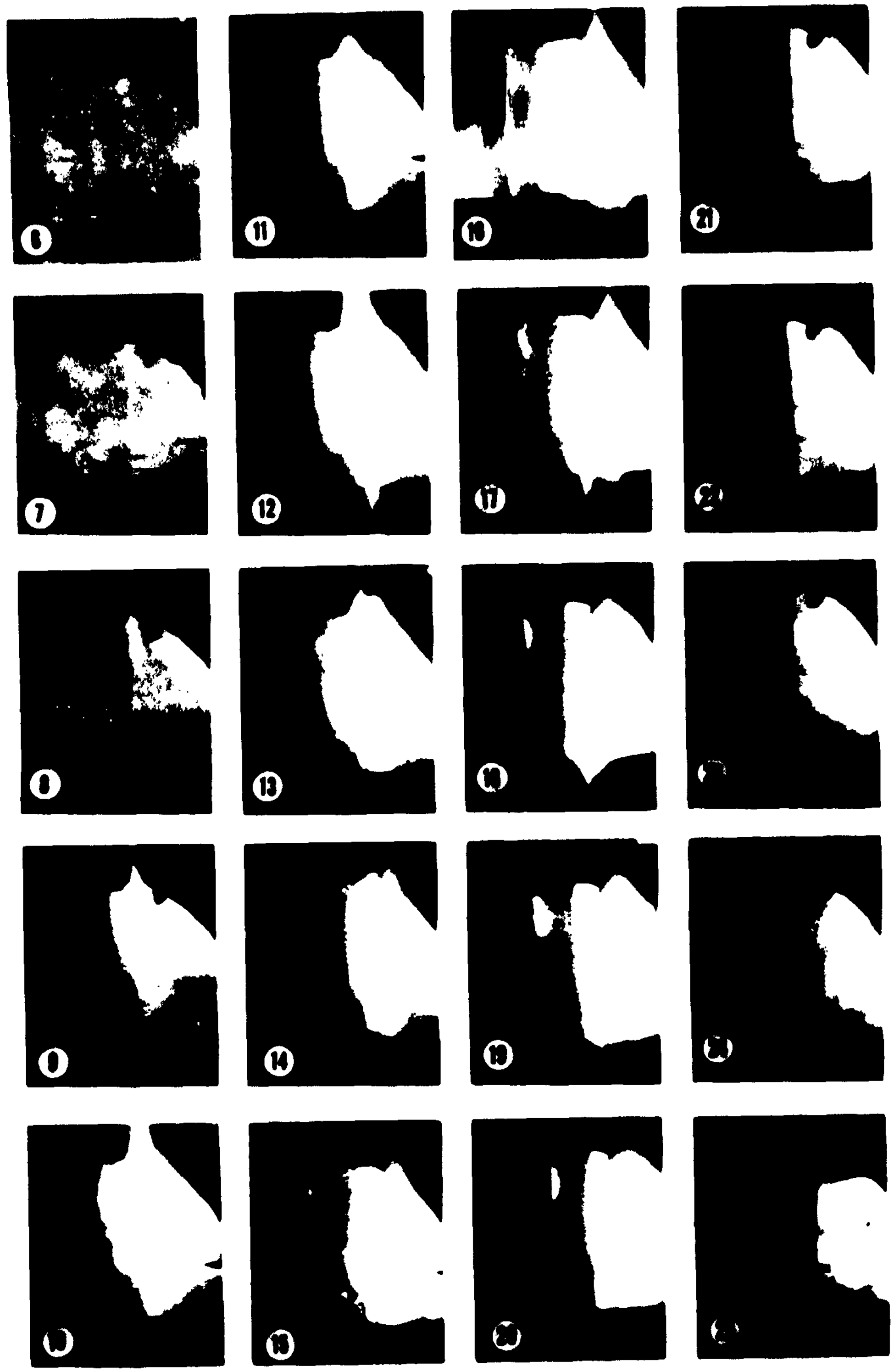


FIGURE 48. HIGH SPEED FRAMING CAMERA SEQUENCE HYPERVELOCITY IMPACT TEST M-316, 0.500 INCH ALUMINUM TARGET, 0.050 INCH ALUMINUM BACKUP PLATE 245,000 FRAMES PER SECOND 4.0 MICROSECONDS PER FRAME.

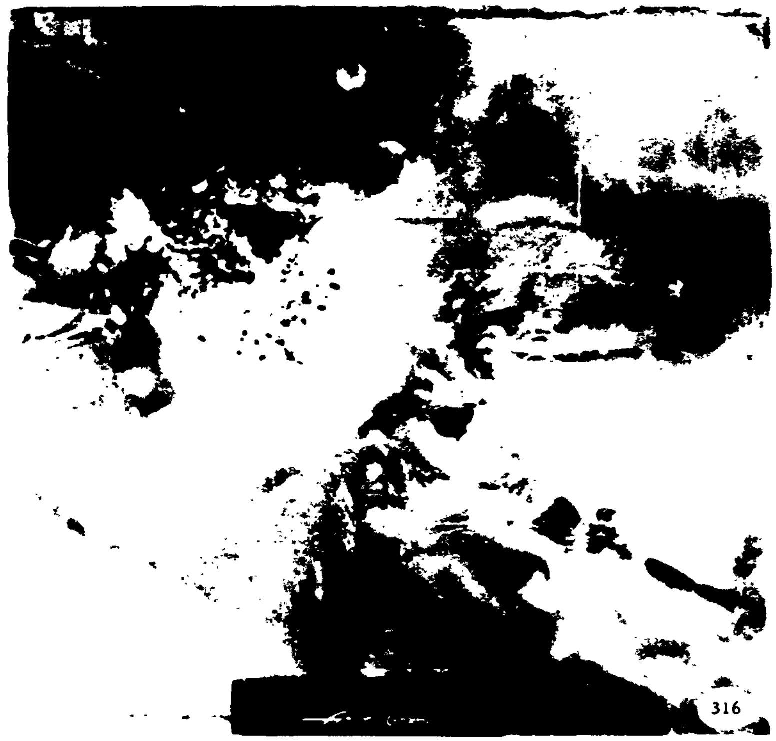


FIGURE 49. TARGET PLATE (BACK SURFACE) AND BACKUP PLATE FROM TEST M-316, 2024-T4 ALUMINUM, 0.500-INCH THICK, 90° OBLIQUITY 0.050-INCH THICK ALUMINUM BACKUP PLATE.

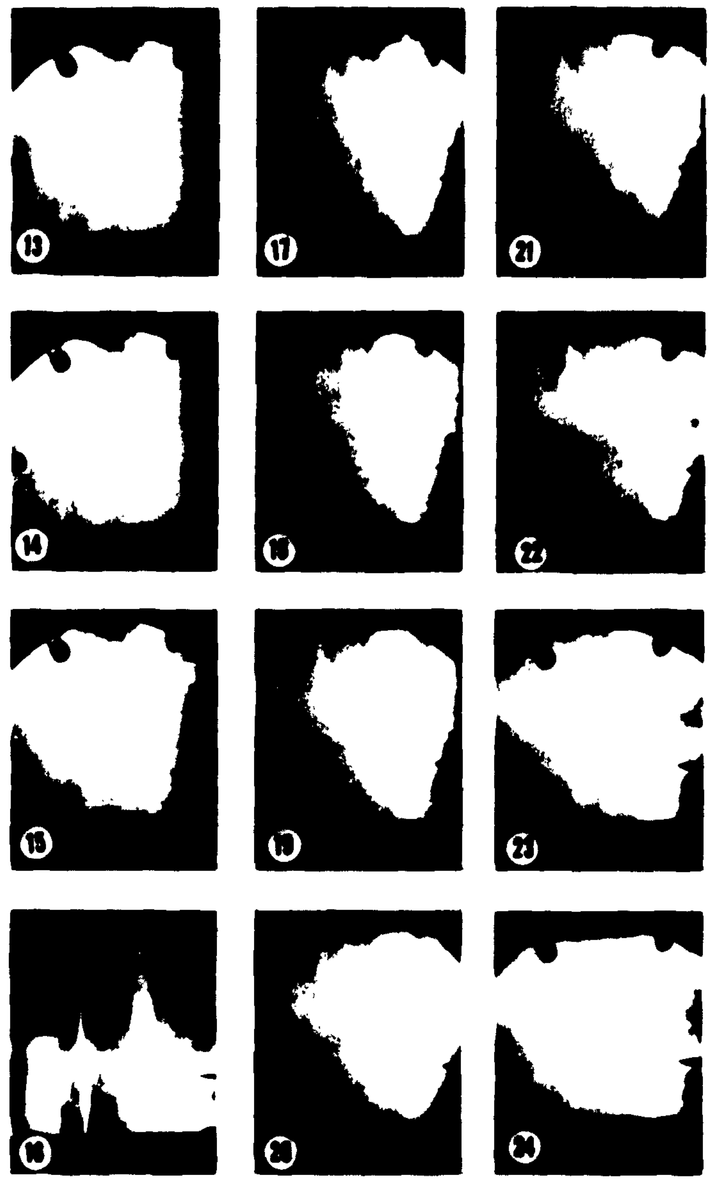


FIGURE 50. HIGH SPEED FRAMING CAMERA SEQUENCE HYPERVELOCITY IMPACT TEST M-312, 1.00 INCH ALUMINUM BACKUP PLATE 150,000 FRAMES PER SECOND 6.9 MICROSECONDS PER FRAME.

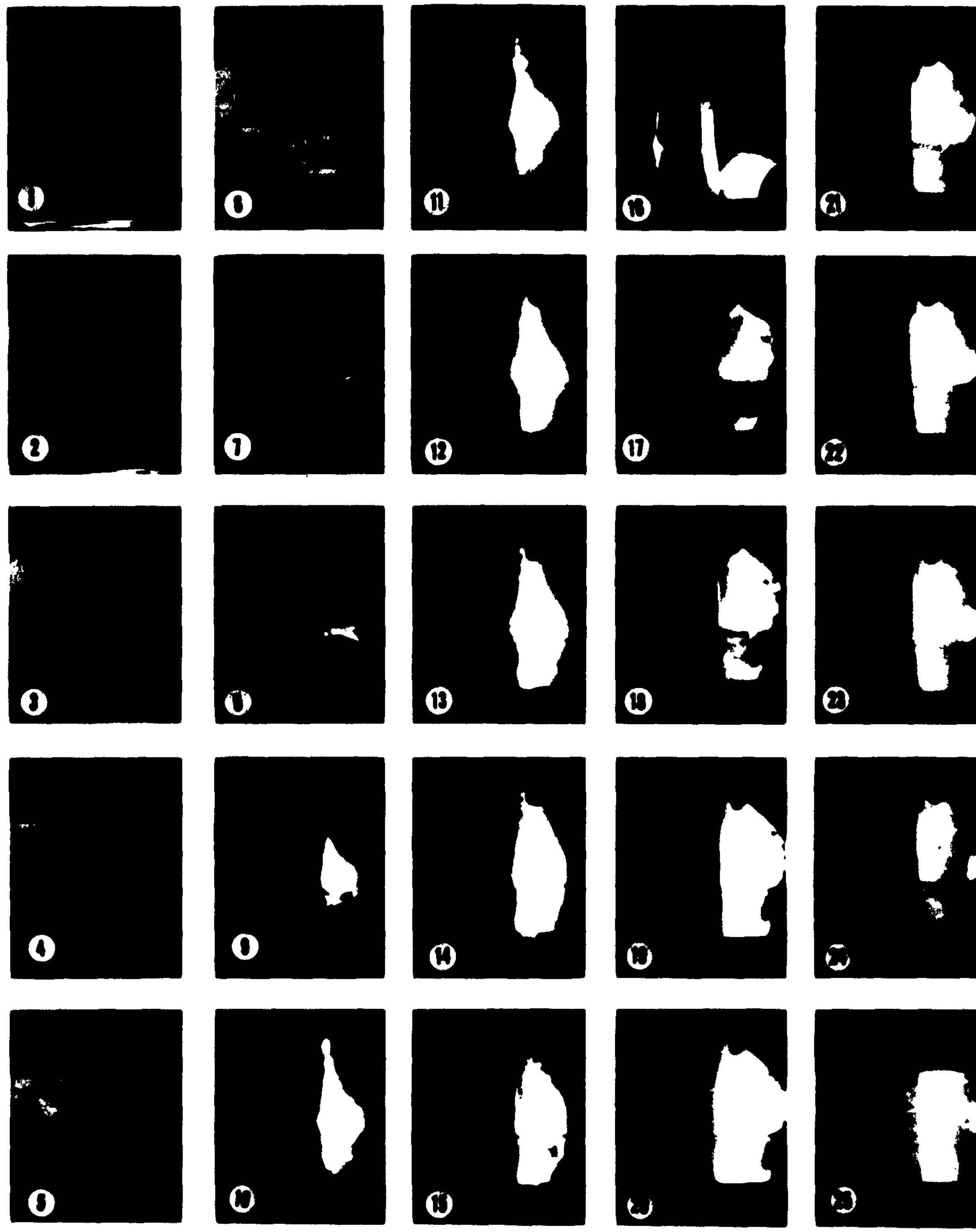


FIGURE 51. HIGH SPEED FRAMING CAMERA SEQUENCE HYPERVELOCITY IMPACT TEST M-305, 1.00 INCH ALUMINUM TARGET, 0.050 INCH ALUMINUM BACKUP PLATE 245,000 FRAMES PER SECOND 4.0 MICROSECONDS PER FRAME.

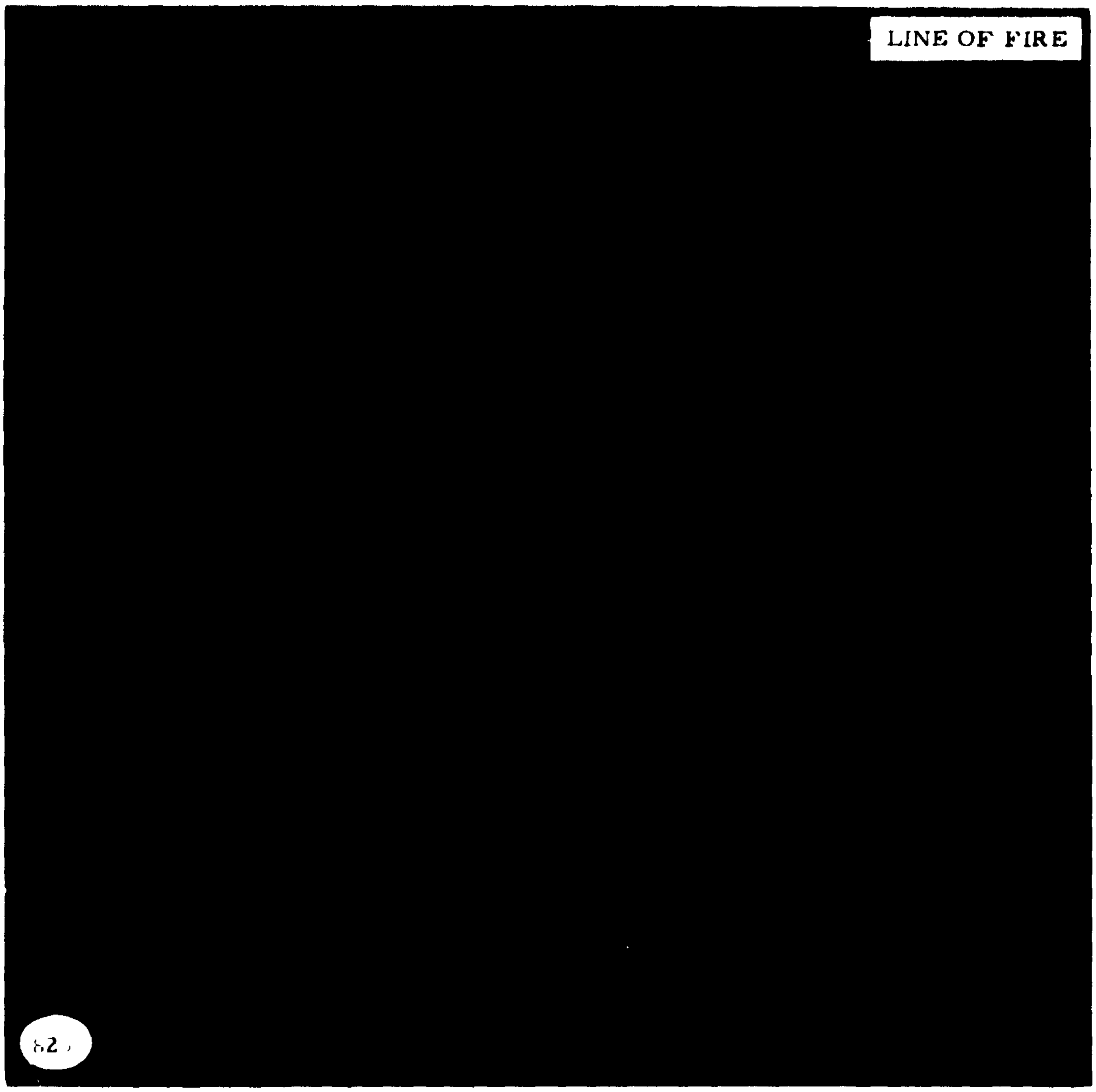
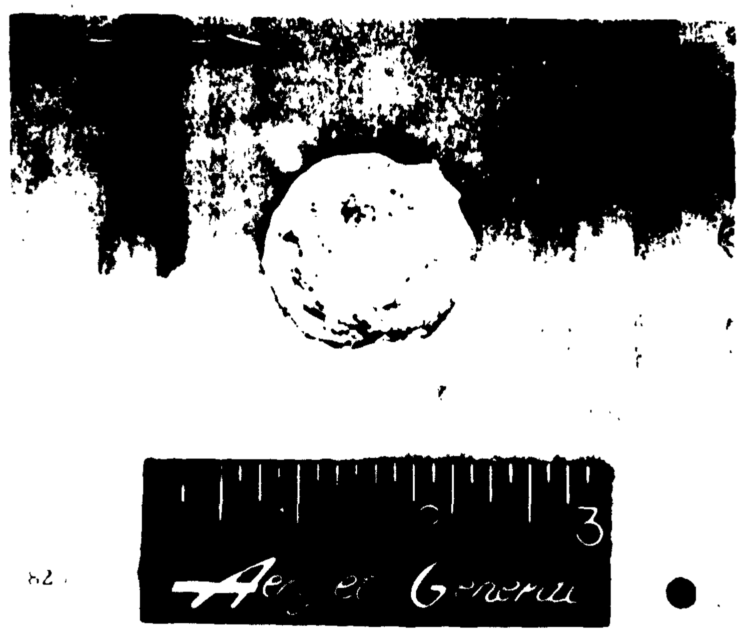


FIGURE 52. SPALL ENVELOPE BEHIND 0.500-INCH ALUMINUM TARGET, 20° OBLIQUITY, APPROXIMATELY 10 MICROSEC AFTER 30,000 FT/SEC IMPACT OF ALUMINUM PROJECTILE

FRONT SURFACE

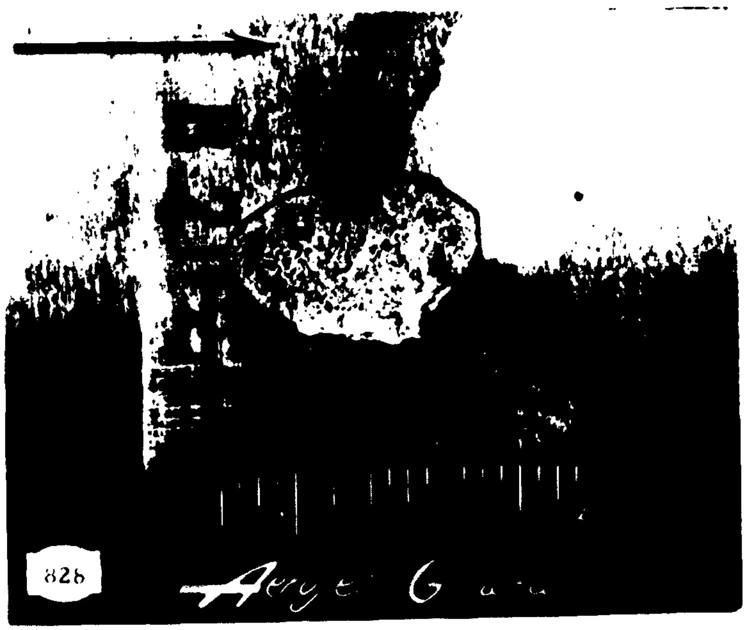


BACK SURFACE

FIGURE 53. FRONT AND BACK SURFACE OF TARGET PLATE FROM TEST NO. 826, 2024-T4 ALUMINUM, 0.500-INCH THICK, 20° OBLIQUITY

FIGURE 54. SPALL ENVELOPE BEHIND 0.500-INCH ALUMINUM TARGET, 20° OBLIQUITY, APPROXIMATELY 15 MICROSEC AFTER 24,000 FT/SEC IMPACT BY ALUMINUM PROJECTILE

FRONT SURFACE



BACK SURFACE

FIGURE 55. FRONT AND BACK SURFACE OF TARGET PLATE FROM TEST NO. 828, 2024-T4 ALUMINUM, 0.500-INCH THICK, 20° OBLIQUITY

FIGURE 56. RADIOGRAPH SHOWING 50° IMPACTS ON 0.500-INCH ALUMINUM TARGET PLATE - ALUMINUM PROJECTILES AT APPROXIMATELY 31,000 FT/SEC

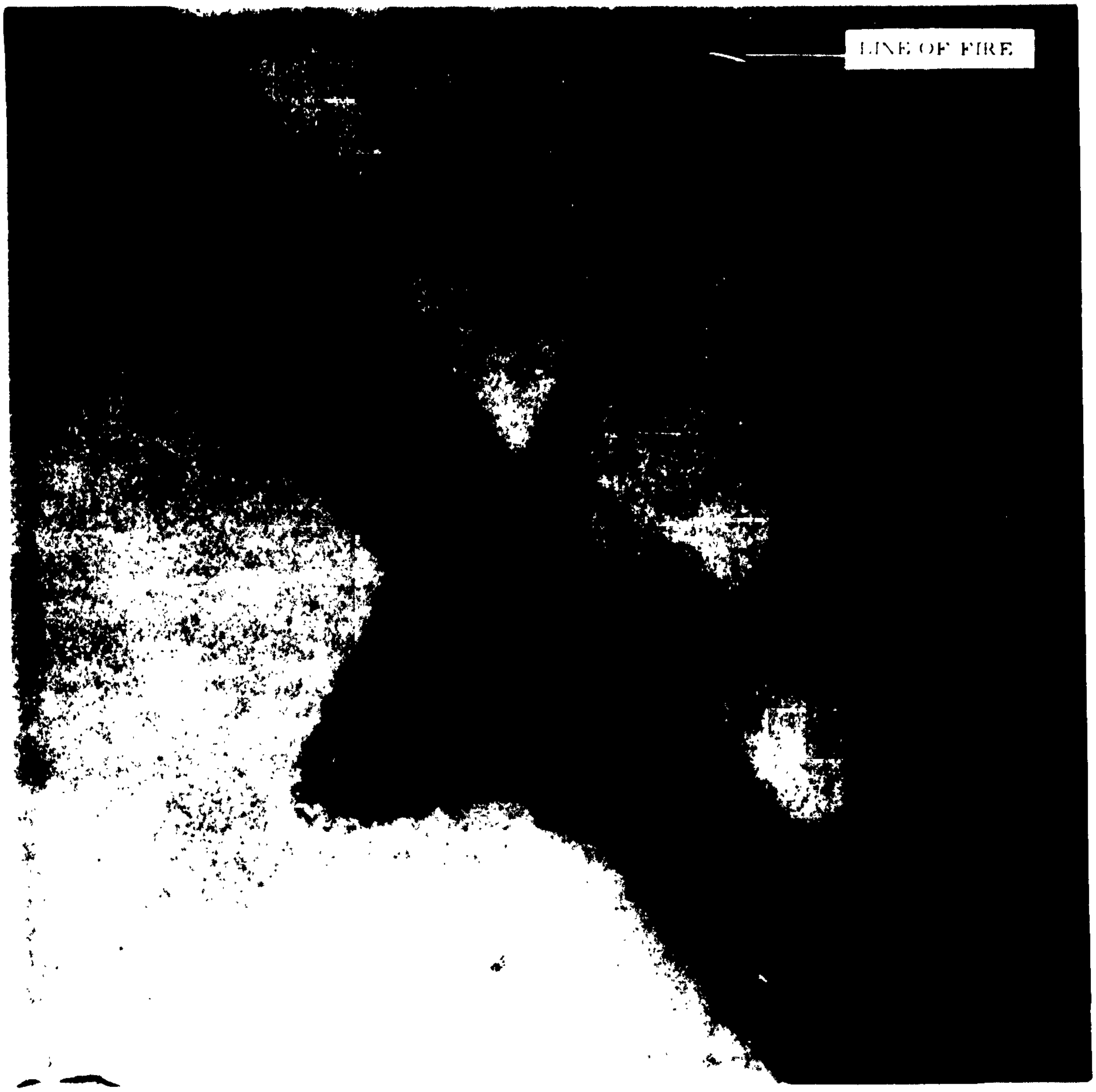


FIGURE 57. SPALL ENVELOPE BEHIND 0.500-INCH ALUMINUM TARGET, 50° OBLIQUITY, APPROXIMATELY 15 MICROSEC AFTER 31,000 FT/SEC IMPACT BY ALUMINUM PROJECTILE

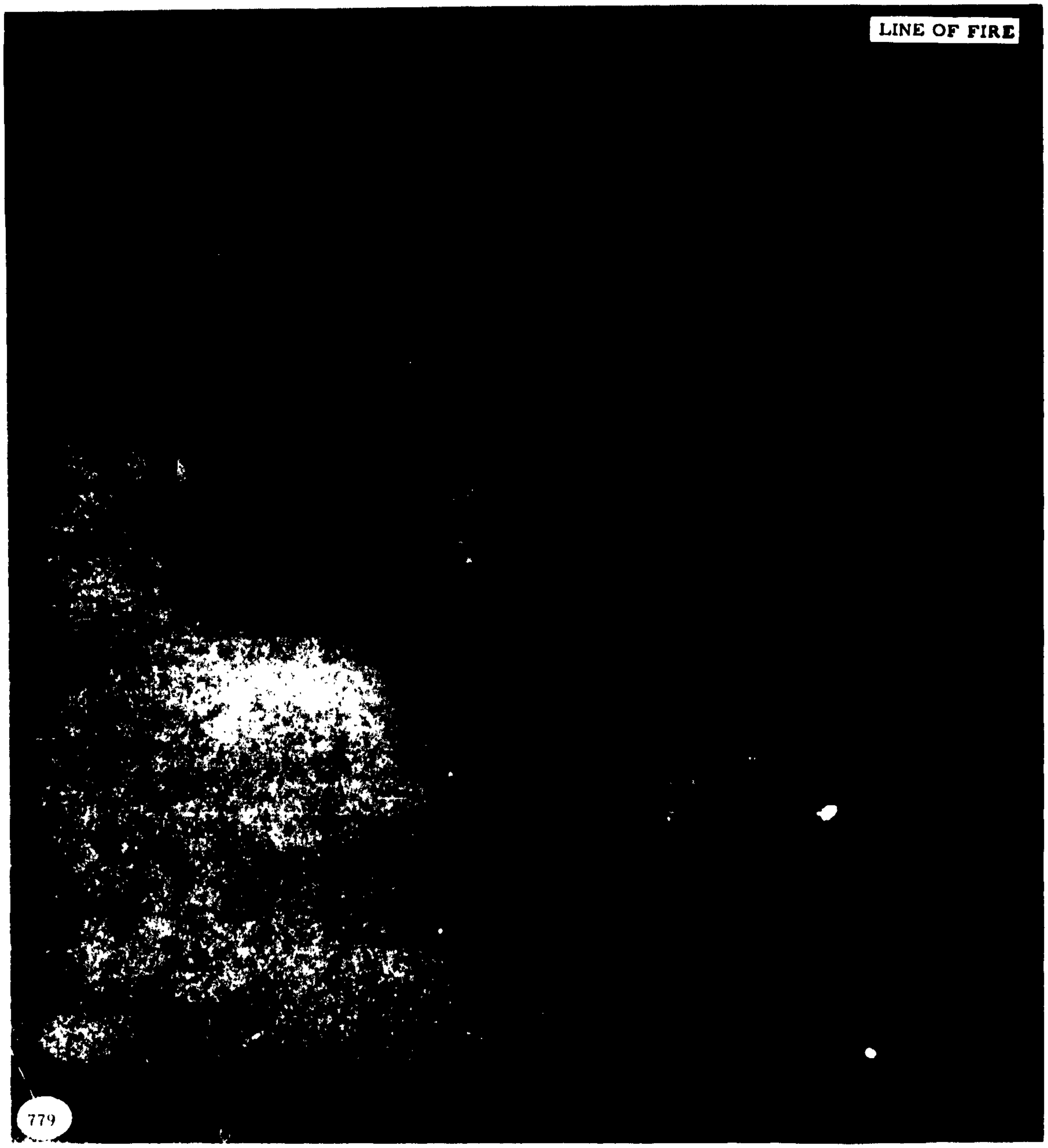


FIGURE 58. SPALL ENVELOPE BEHIND 0.500-INCH ALUMINUM TARGET, 50° OBLIQUITY, APPROXIMATELY 12 MICROSEC AFTER 31,000 FT/SEC INITIAL IMPACT BY ALUMINUM PROJECTILE

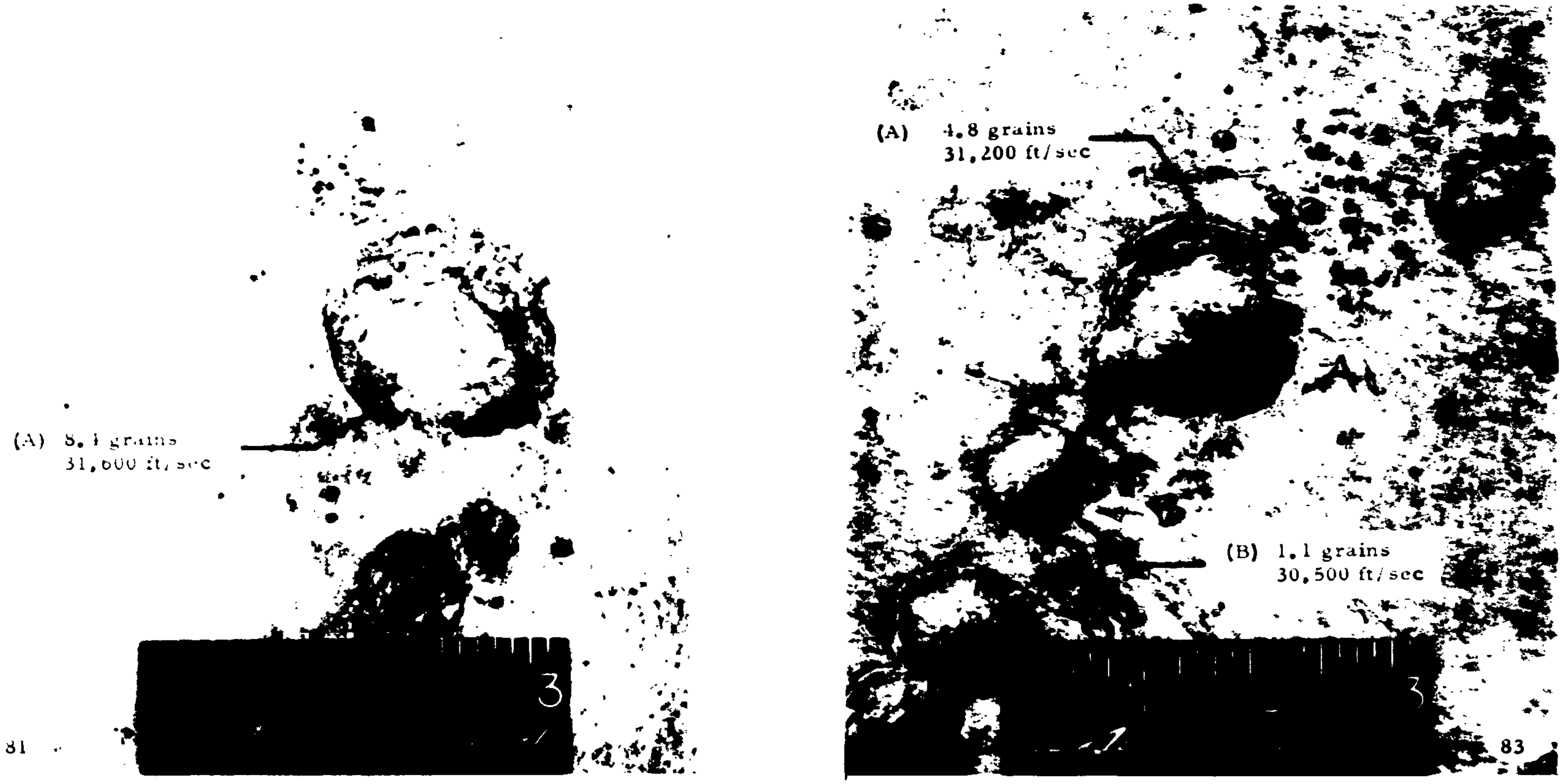


FIGURE 59. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-81 AND M-83.

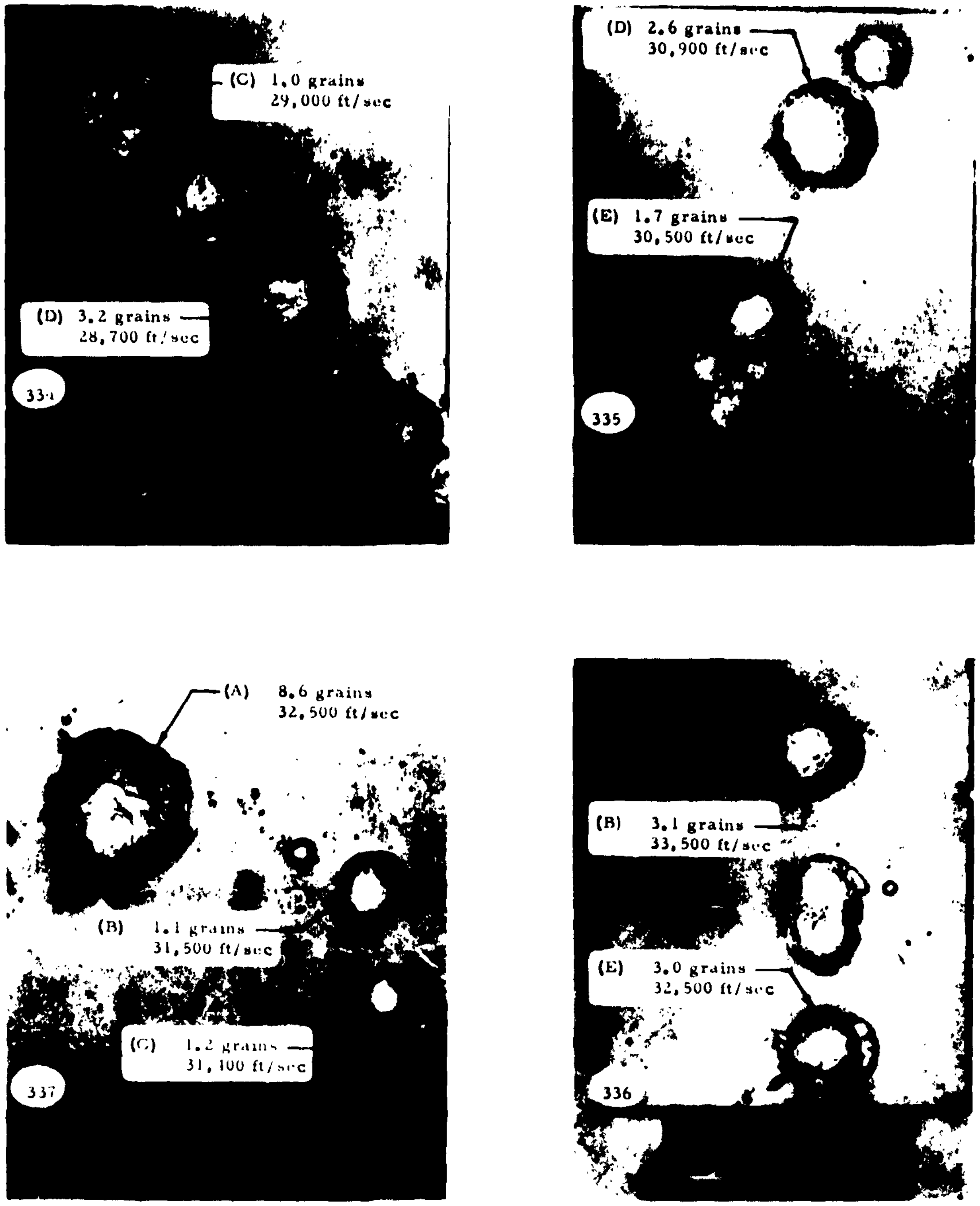


FIGURE 60. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-334, M-335, M-336, and M-337.

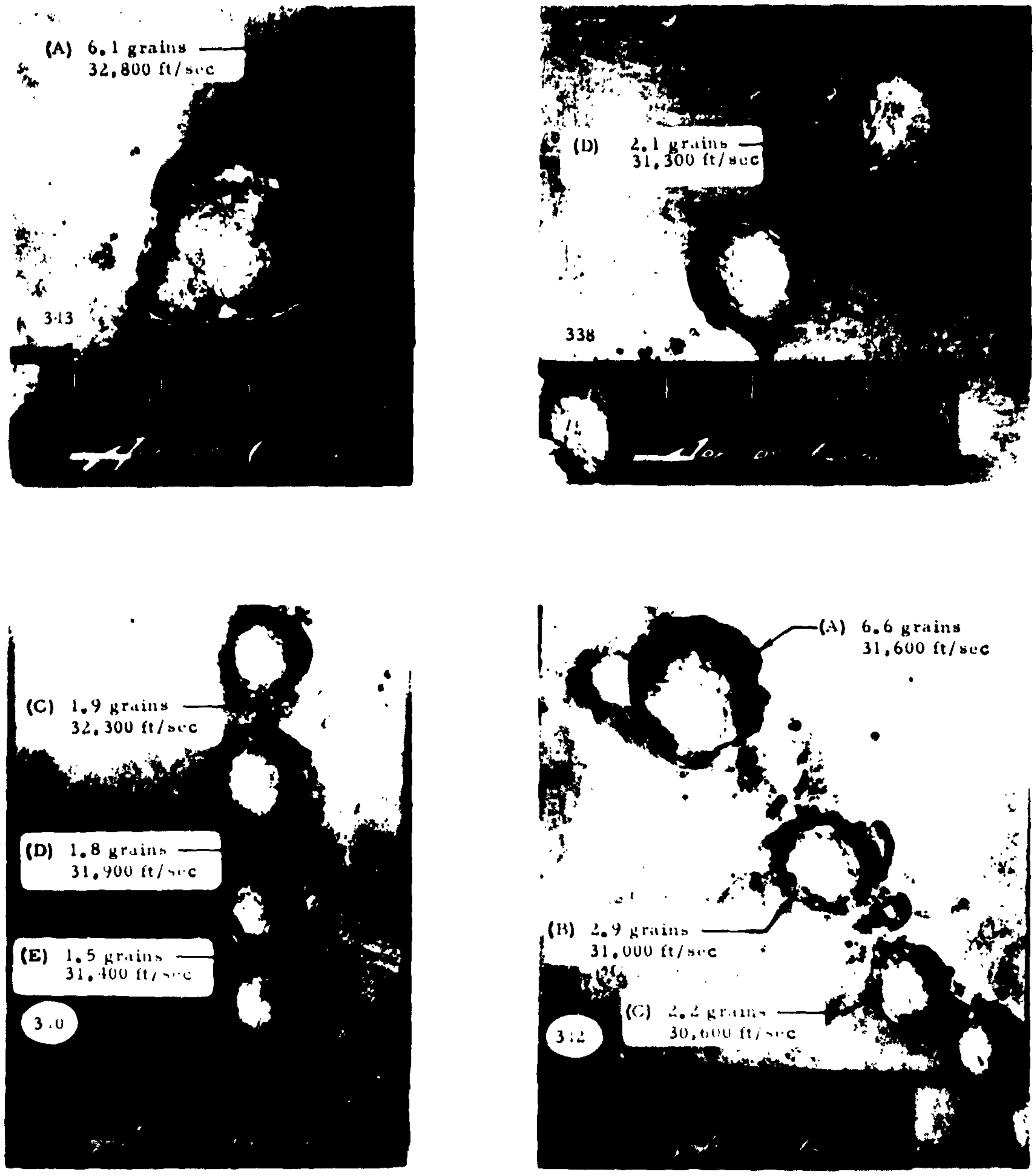


FIGURE 61. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-338, M-340, M-342 AND M-343.

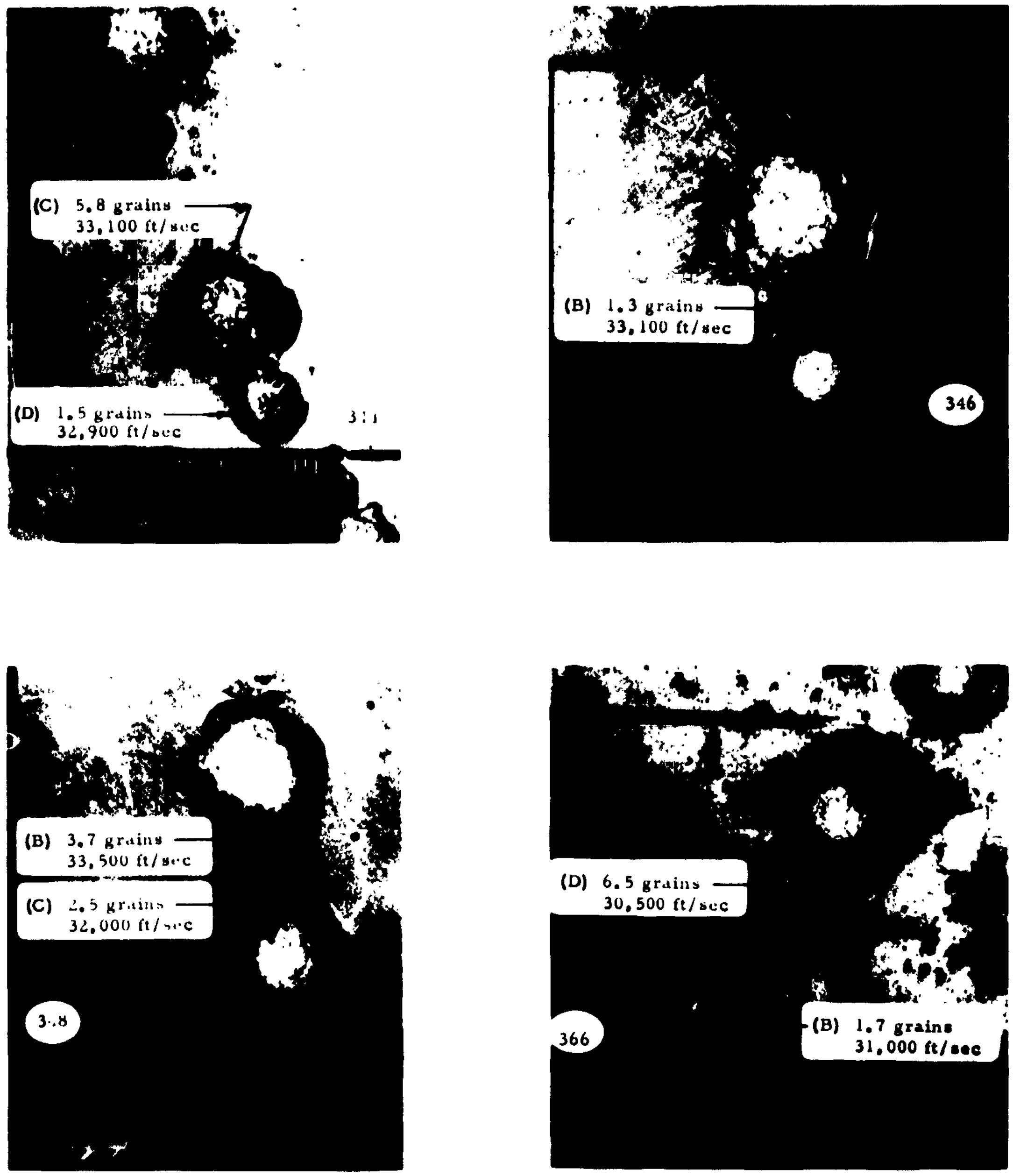


FIGURE 62. TARGET PLATES, 2024-T4
ALUMINUM, 4.0-INCH THICK,
90° OBLIQUITY, TEST NO. M-344,
M-346, M-348 and M-366.

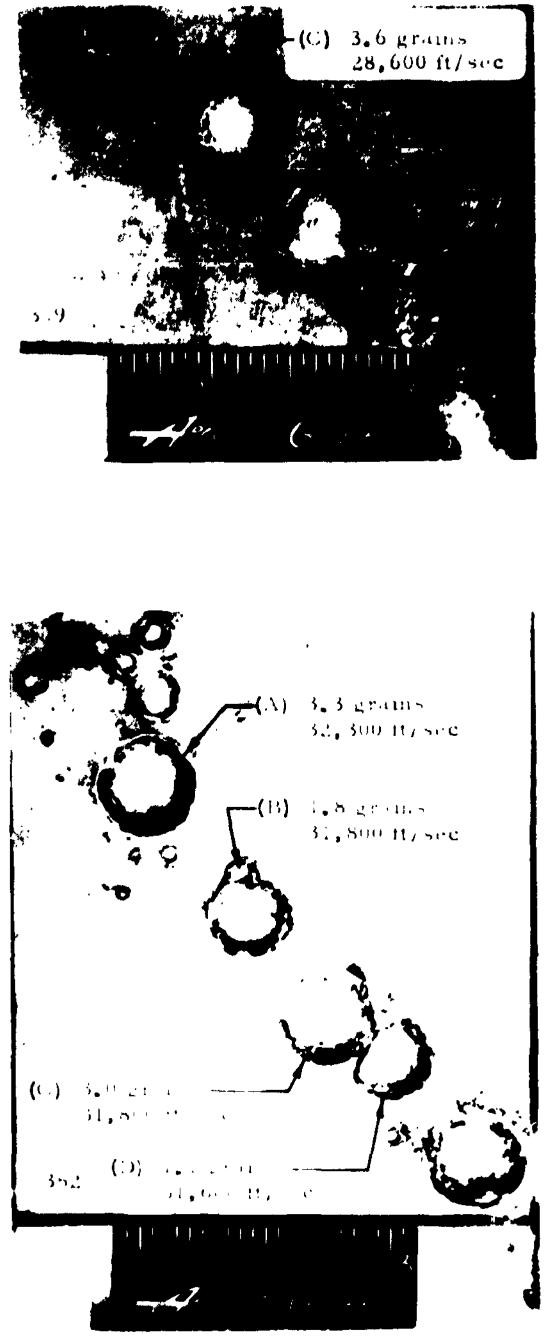
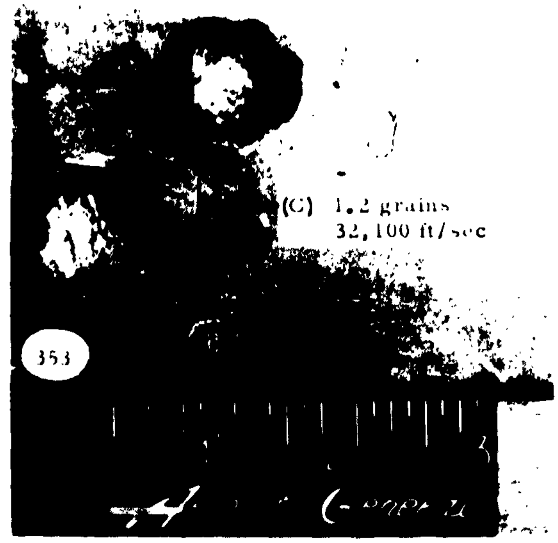


FIGURE 63. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-349, M-352.



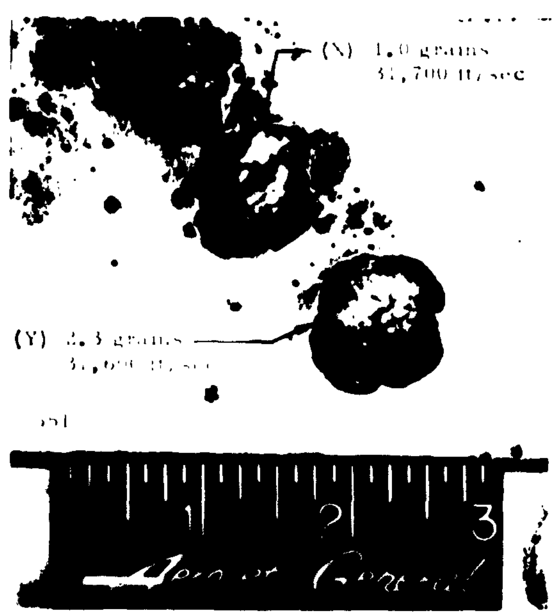


FIGURE 64. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-353 AND M-351.

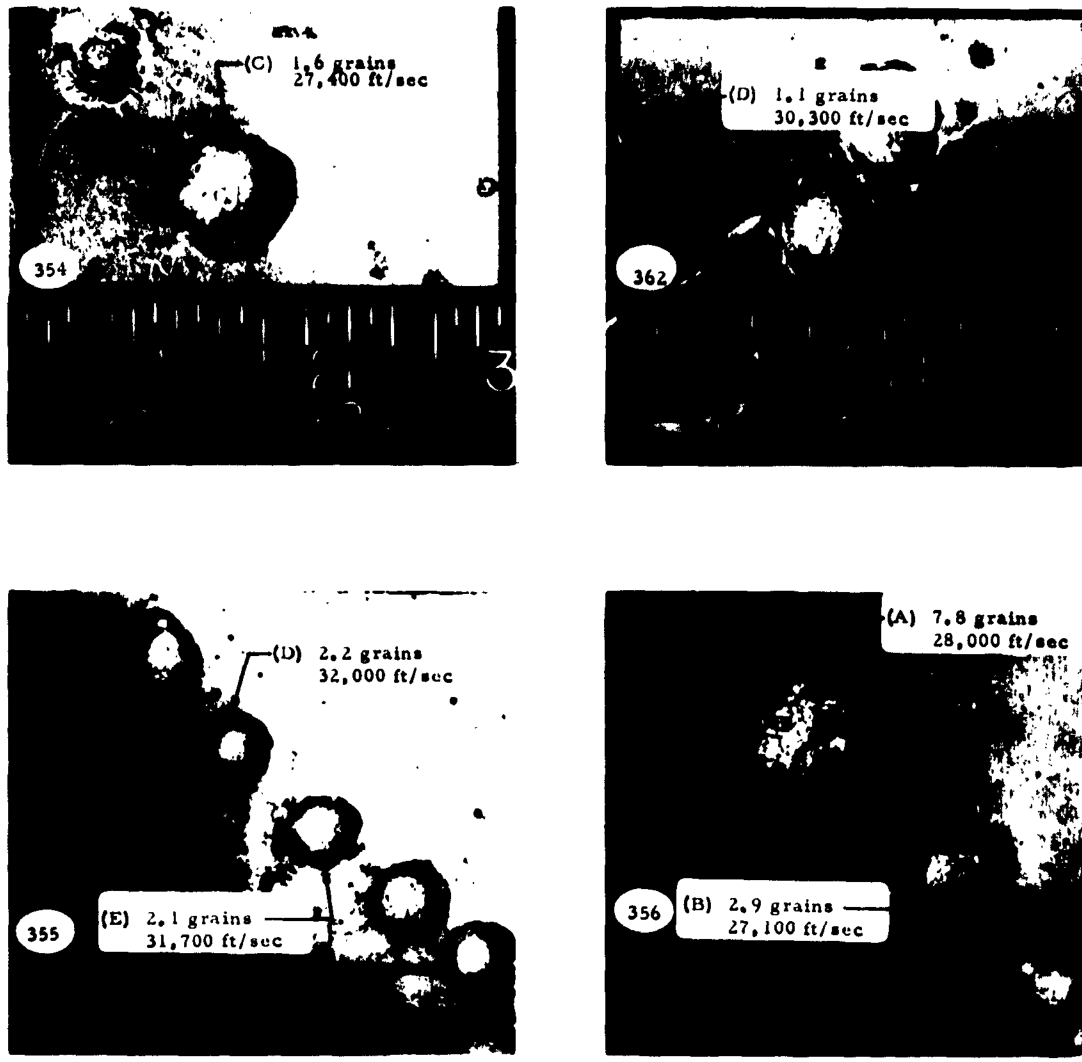


FIGURE 65. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-354, M-355, M-356 and M-362.

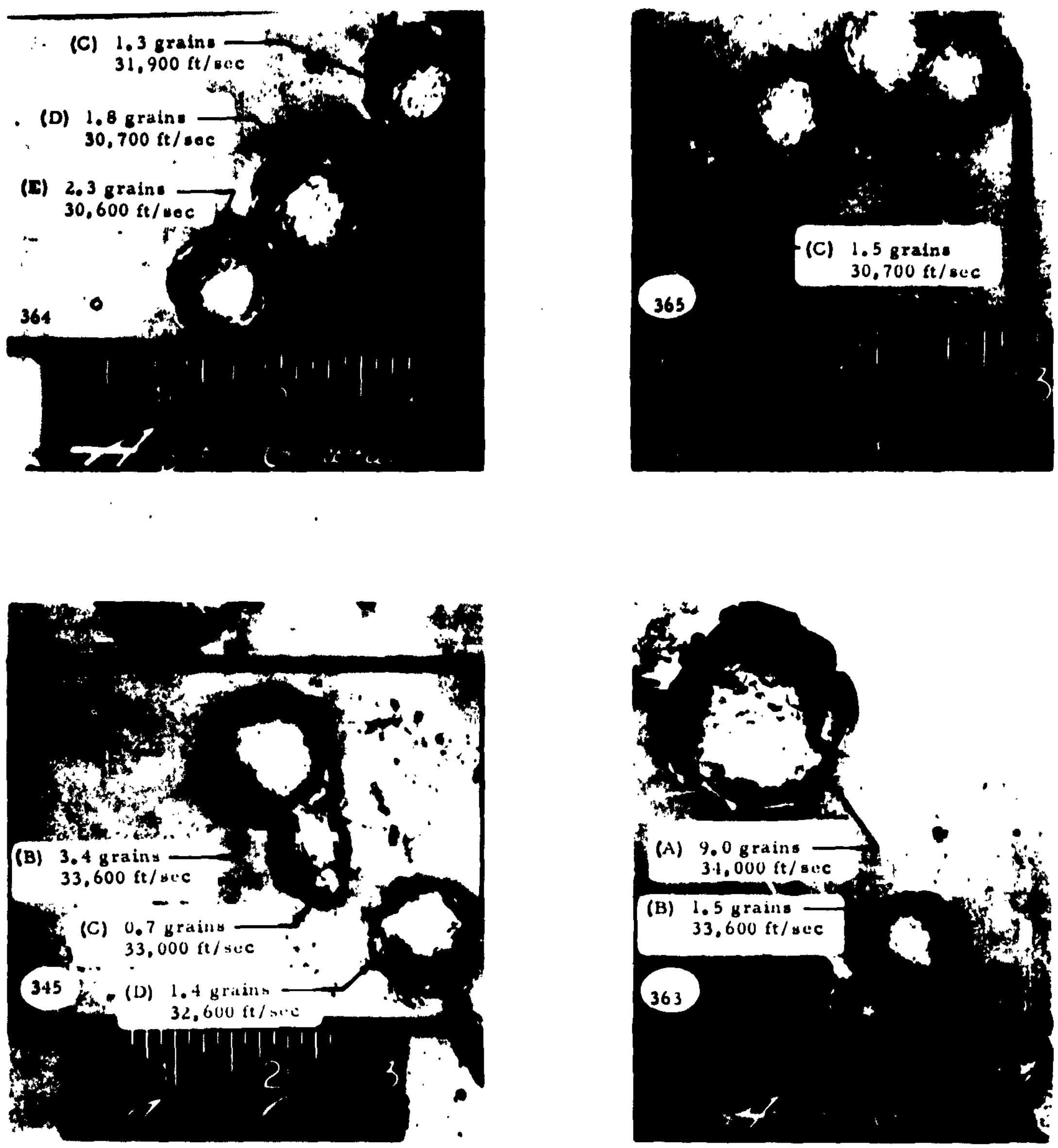


FIGURE 66. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-345, M-363, M-364 and M-365.

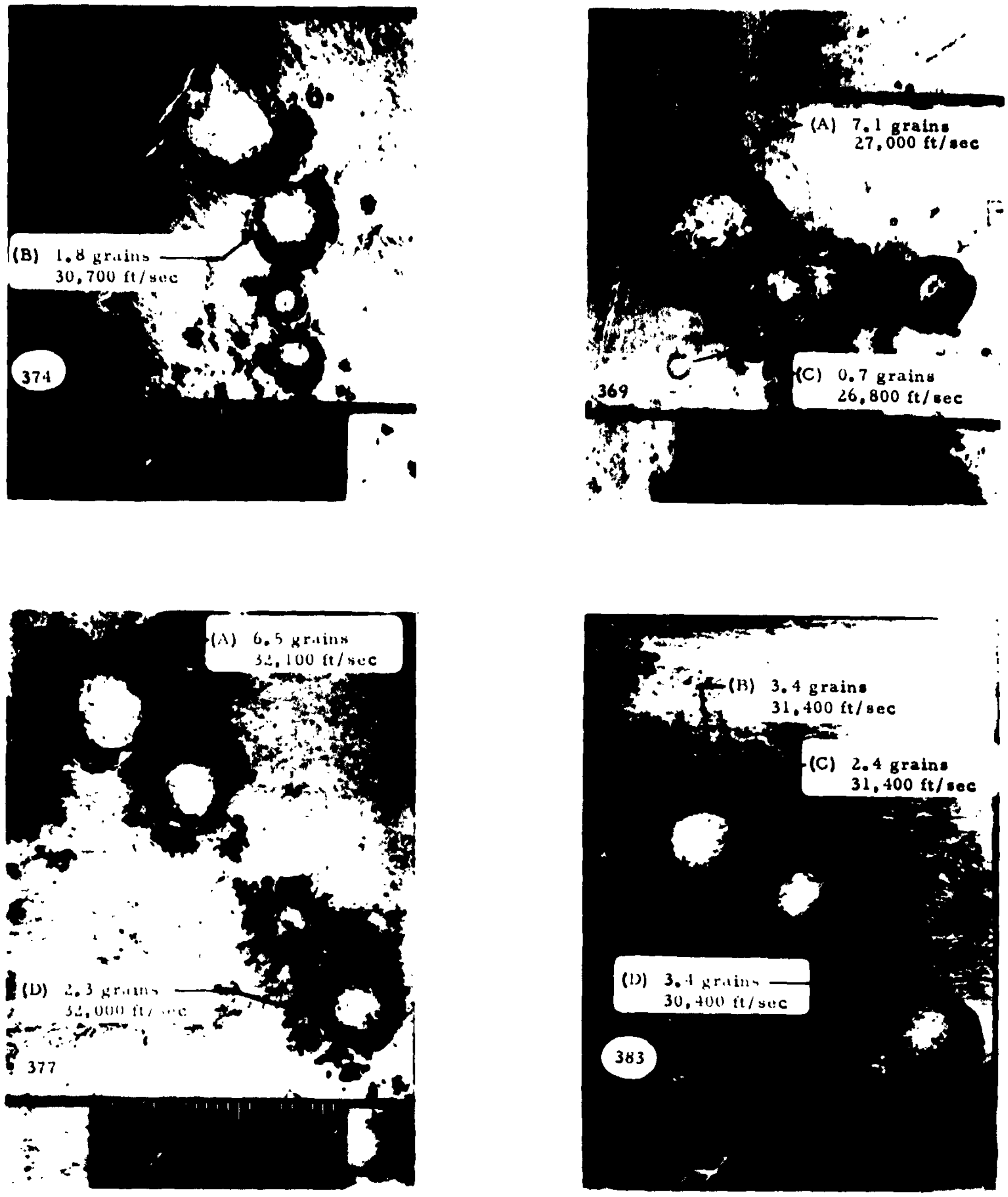


FIGURE 67. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-369, M-374, M-377 AND M-383.

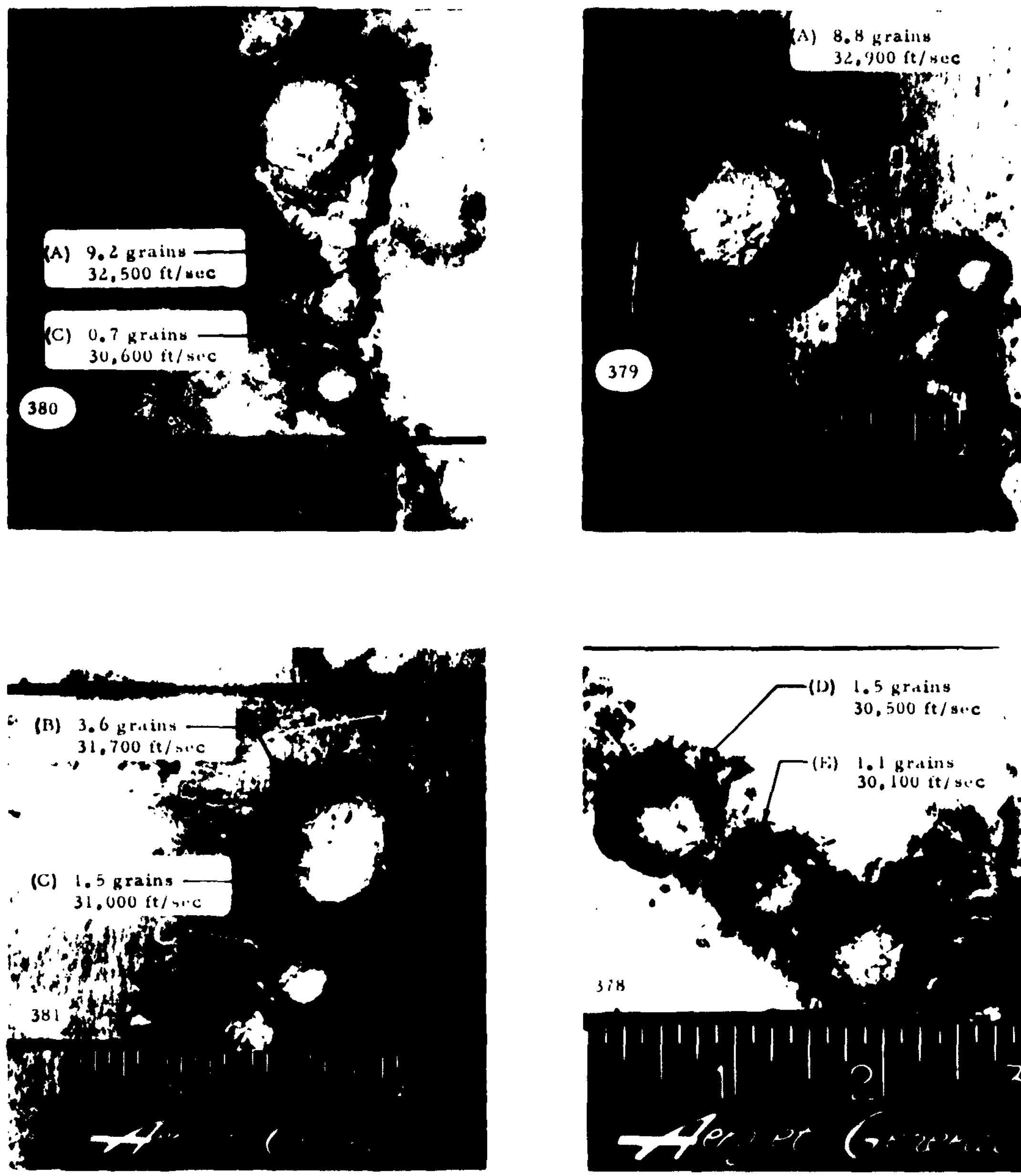


FIGURE 68. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-378, M-379, M-380 and M-381.

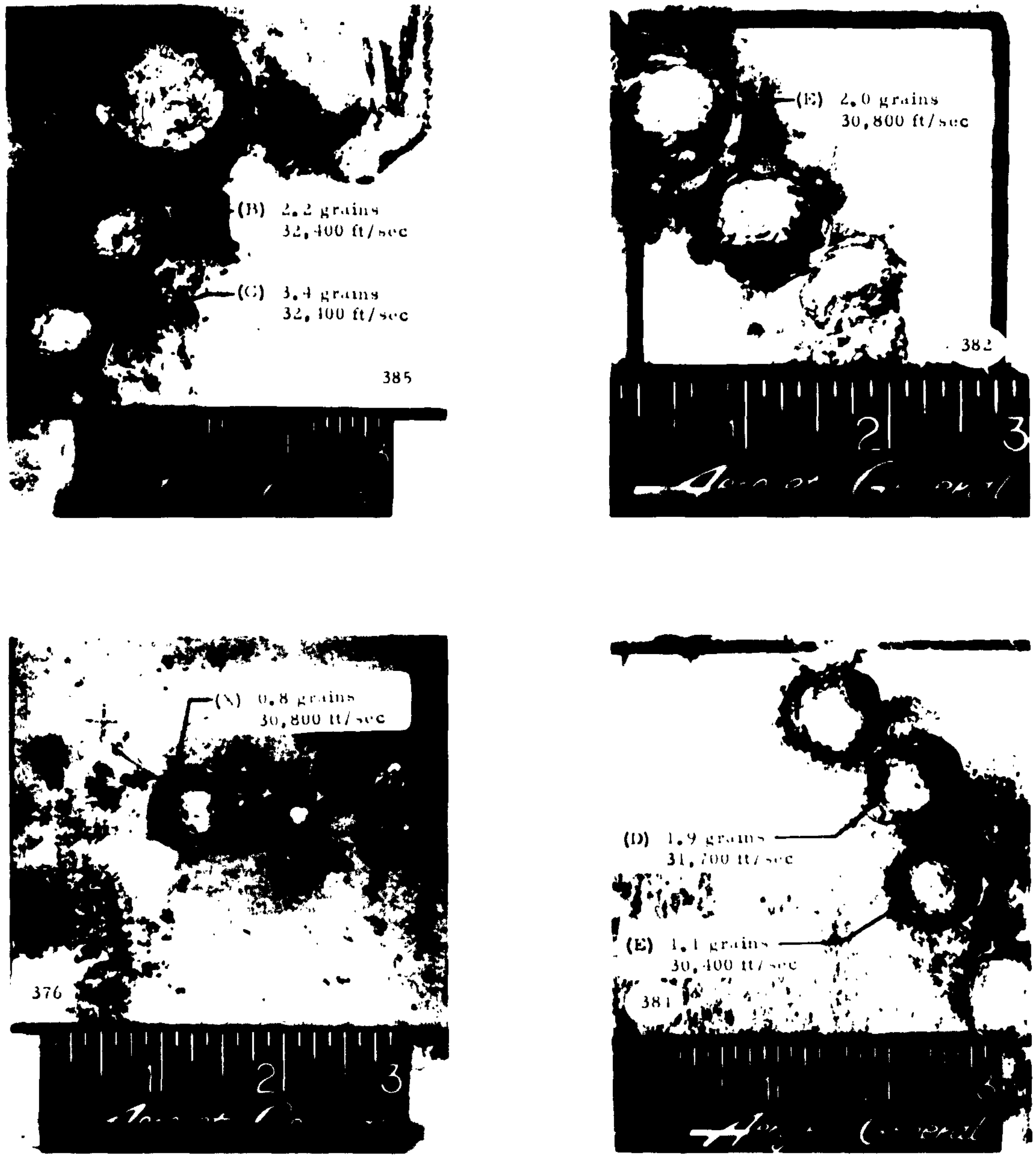


FIGURE 69. TARGET PLATES, 2024-T4 ALUMINUM, 4.0-INCH THICK, 90° OBLIQUITY, TEST NO. M-376, M-382, M-384 AND M-385.

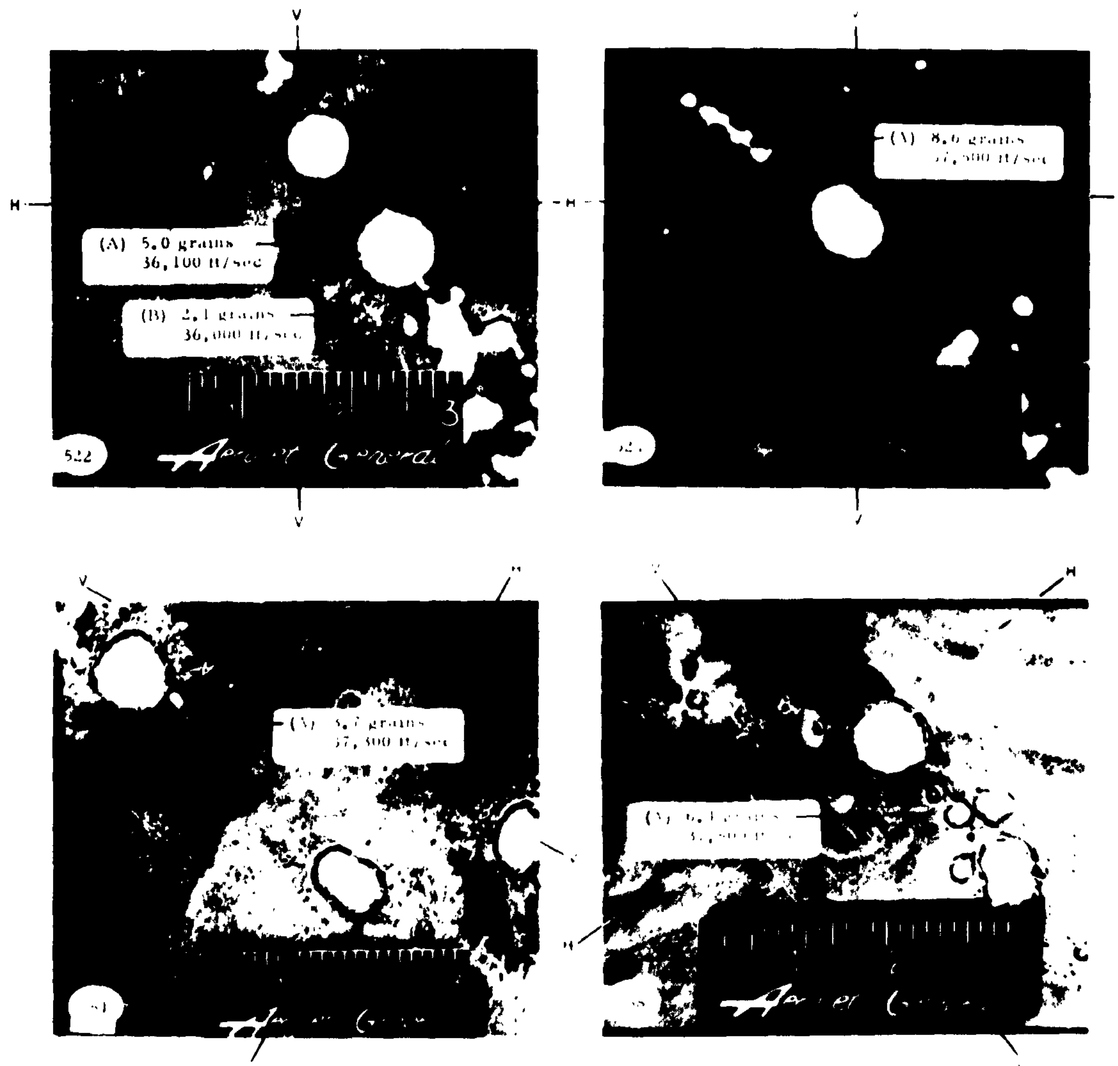


FIGURE 70. TARGET PLATE, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-324, M-451, M-458 AND M-522.

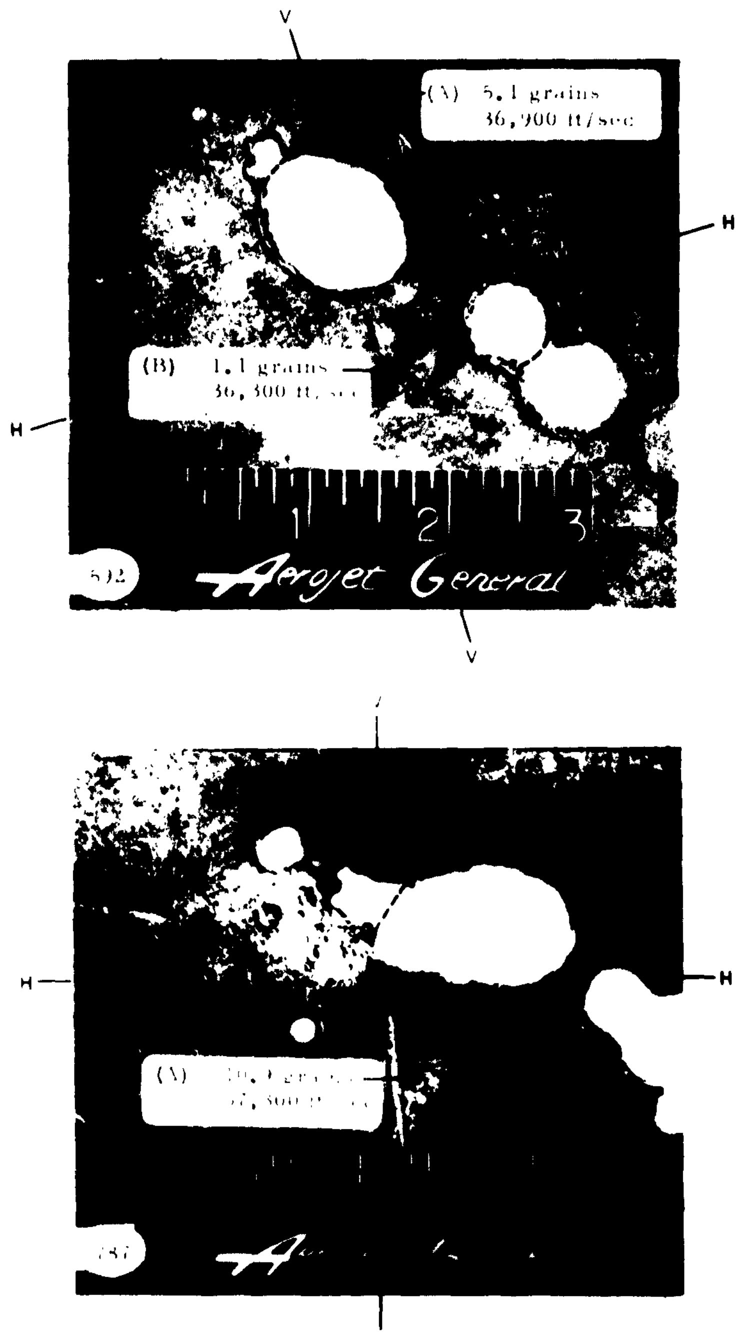


FIGURE 71. TARGET PLATES, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-592, AND M-787.

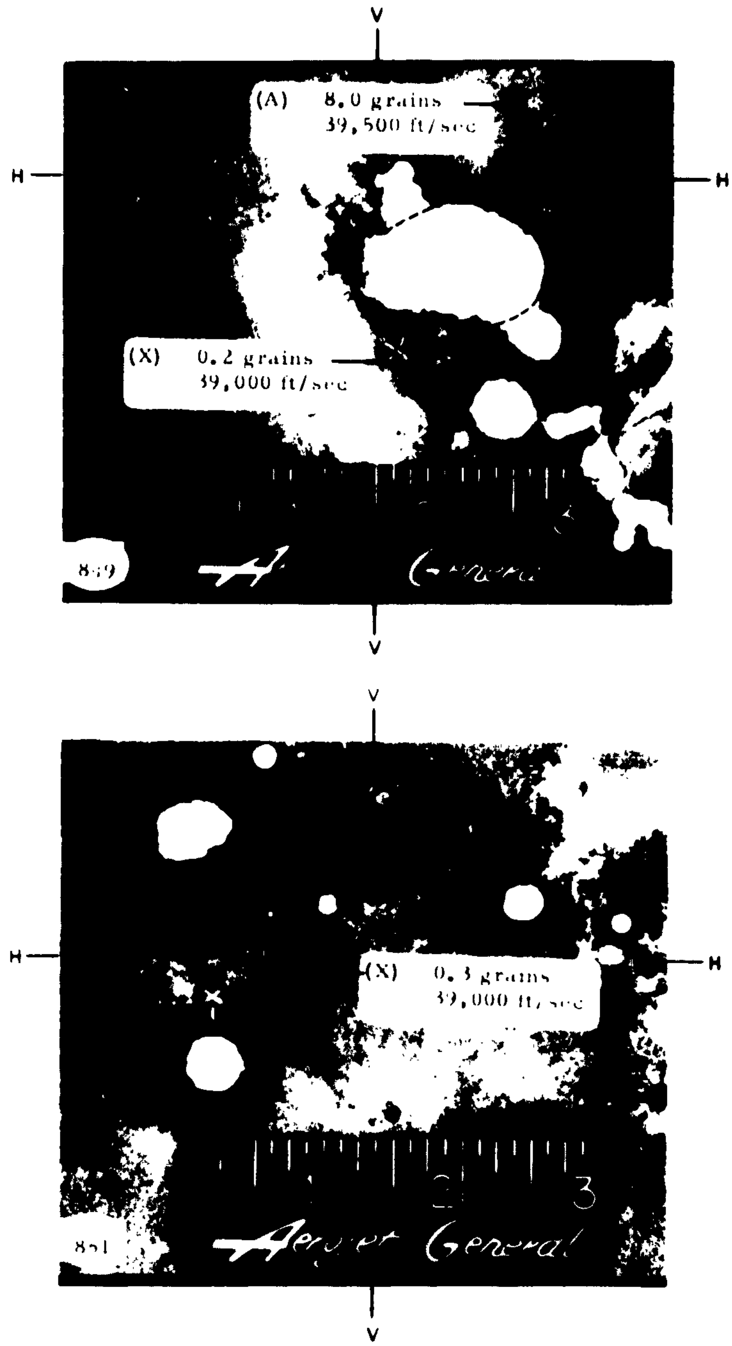


FIGURE 72. TARGET PLATES, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-849 AND M-851.

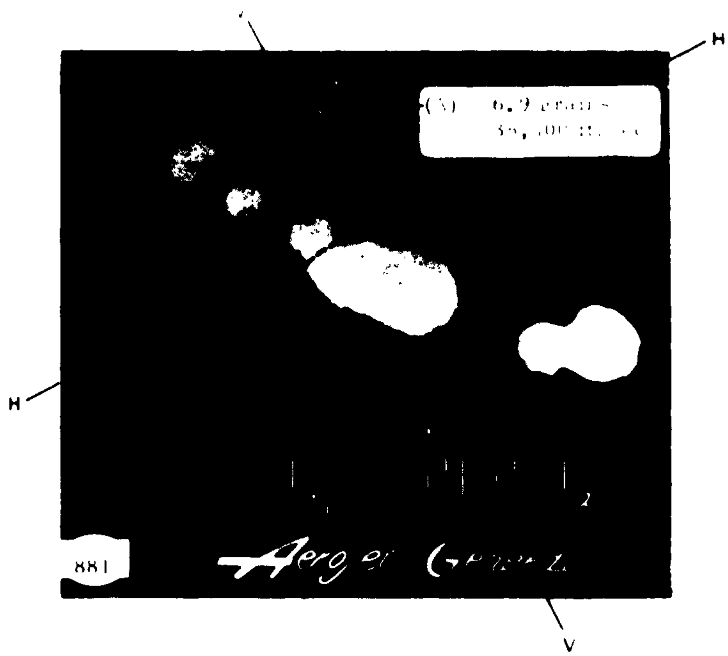


FIGURE 73. TARGET PLATES, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-843 AND M-881.

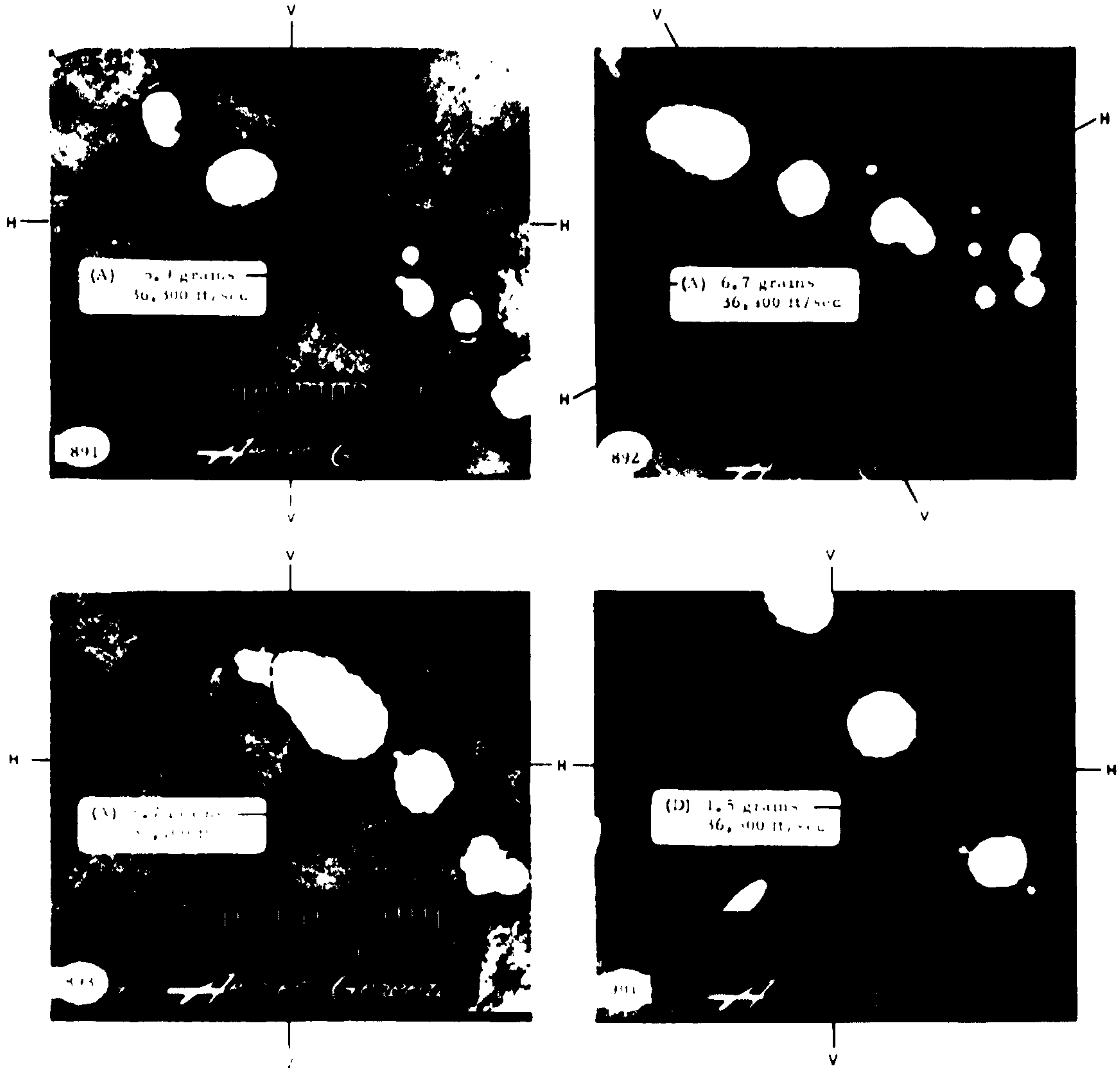


FIGURE 74. TARGET PLATES, 2024-T4
ALUMINUM, 0.100-INCH THICK,
90° OBLIQUITY, TEST NO. M-891,
M-892, M-893, AND M-901.

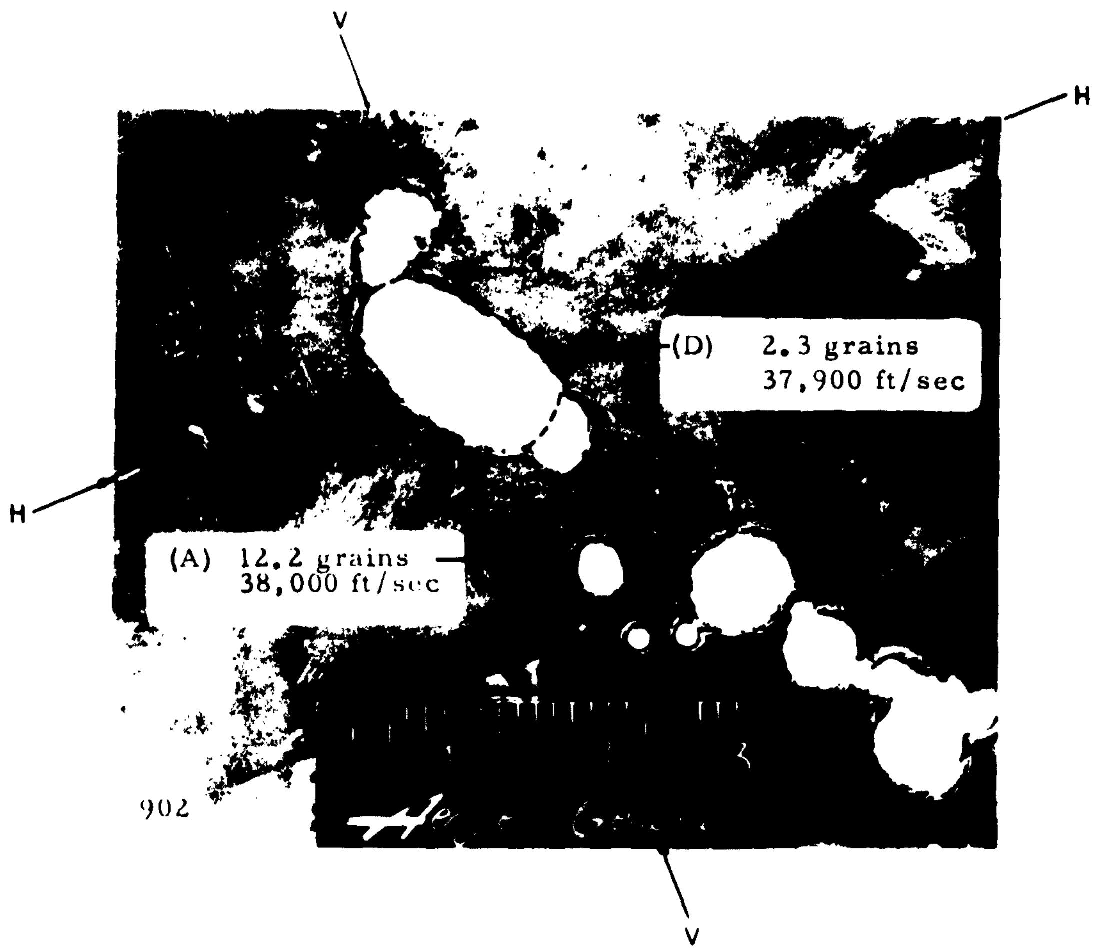


FIGURE 75. TARGET PLATE, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-902.

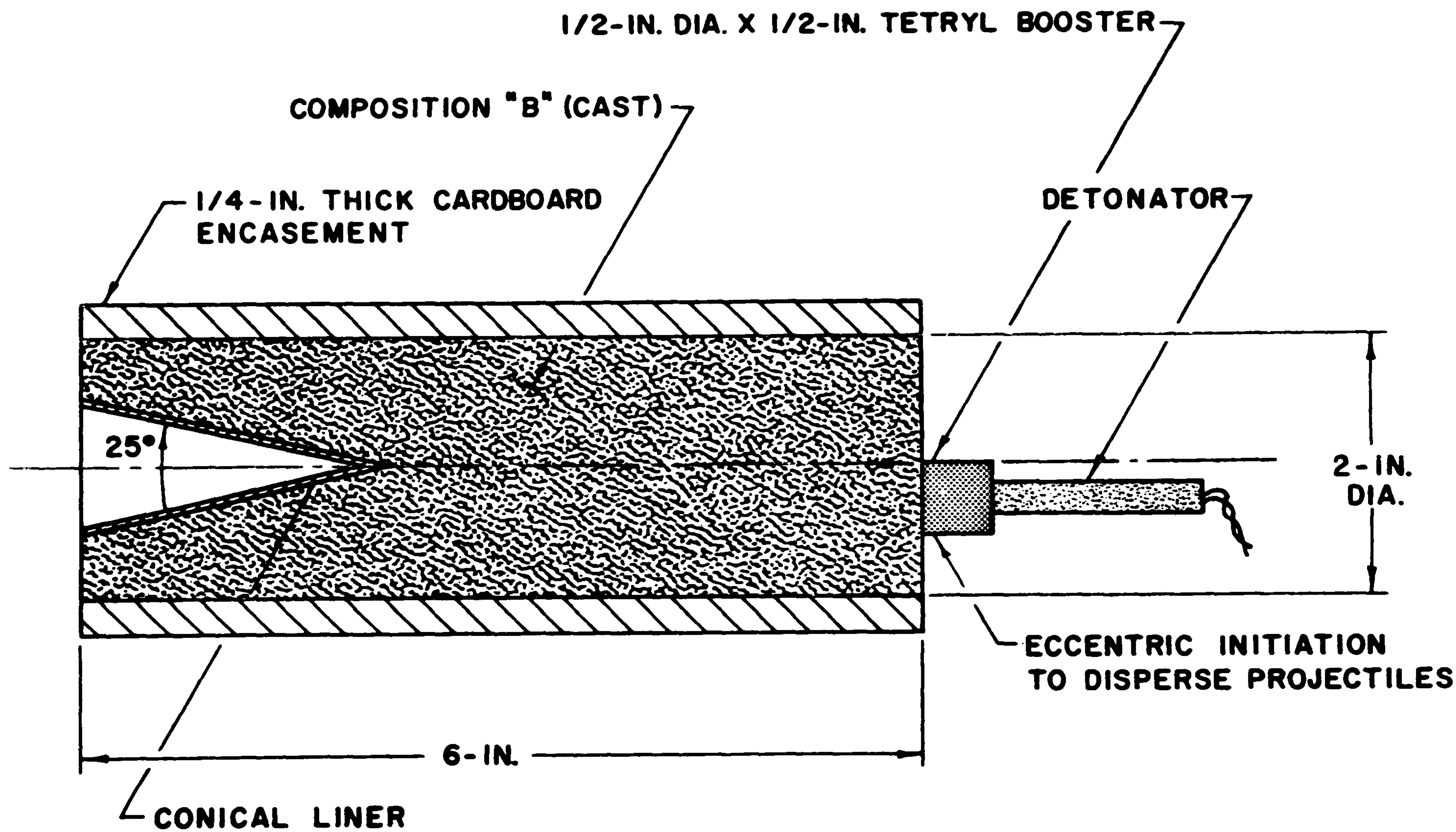


FIGURE 76 - **SHAPED CHARGE EXPLOSIVE PROJECTOR EMPLOYING 25° LINER**

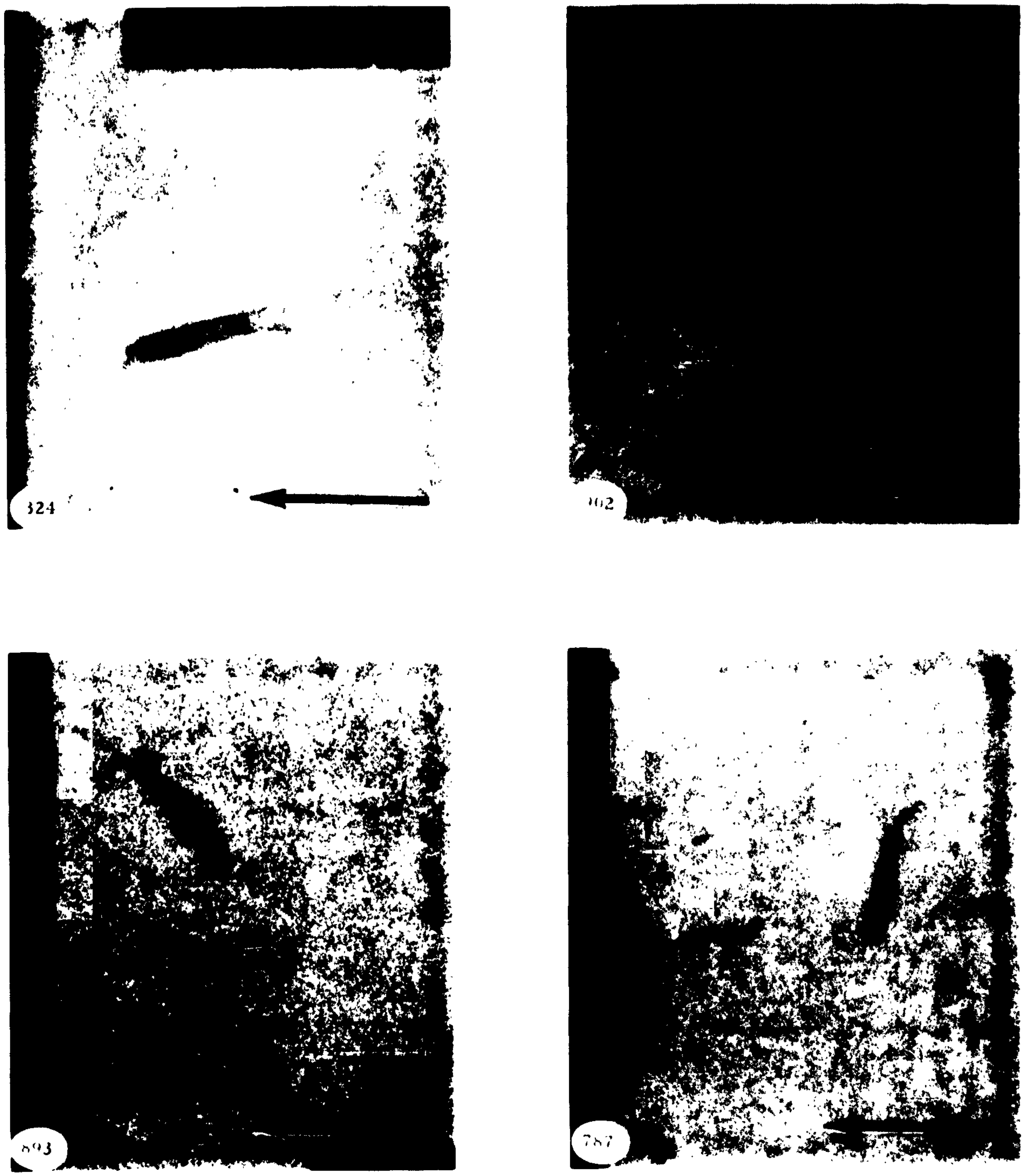


FIGURE 77. AREAS OF LOW DENSITY,
ALUMINUM PROJECTILES,
35,000-39,000 FT /SEC.

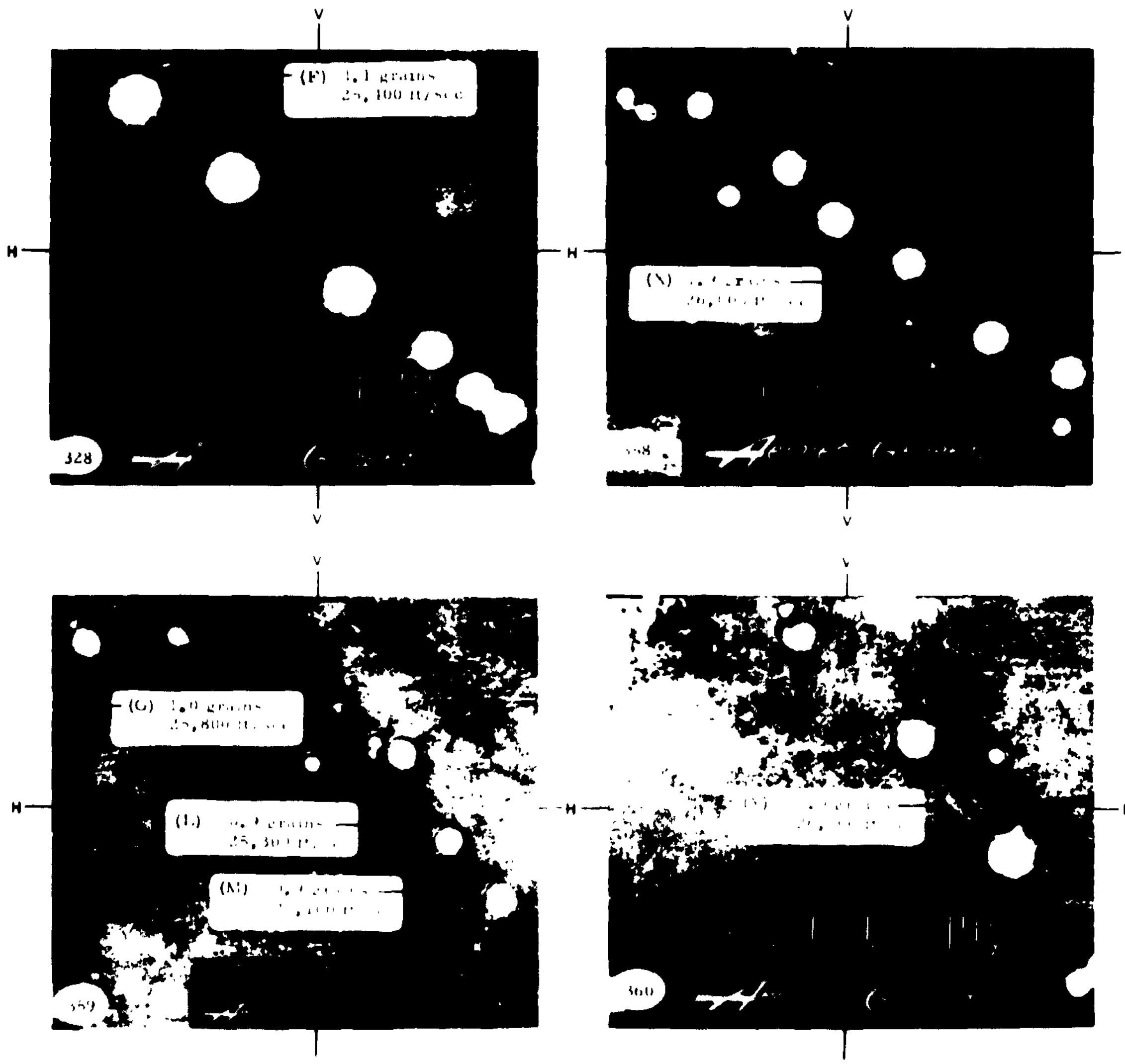
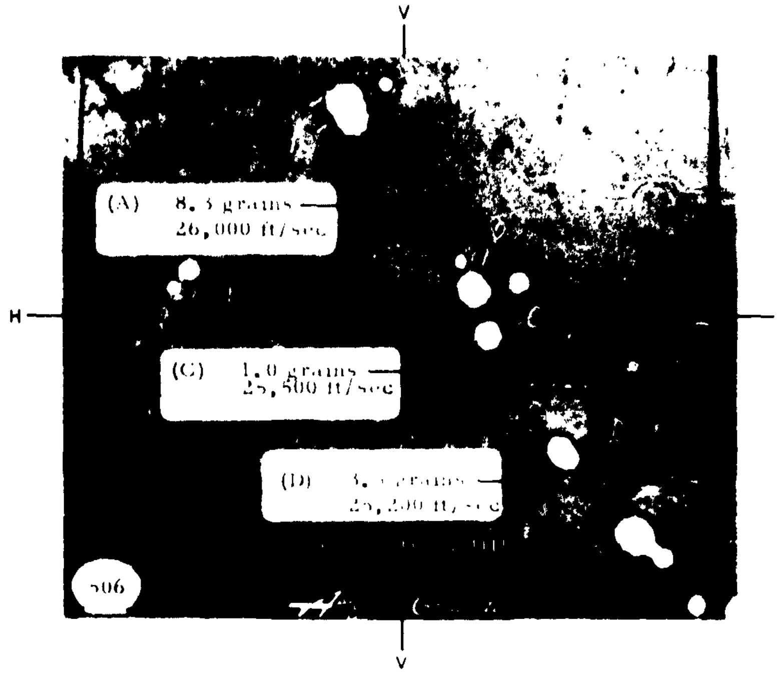


FIGURE 78. TARGET PLATES, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-328, M-358, M-359 AND M-360.



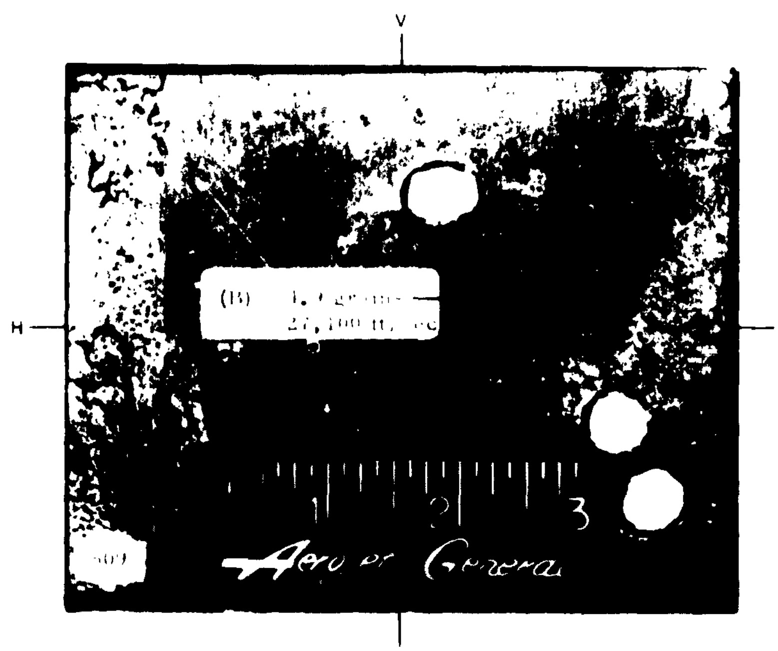


FIGURE 79. TARGET PLATES, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90^{0} OBLIQUITY, TEST NO. M-506 and M-509.

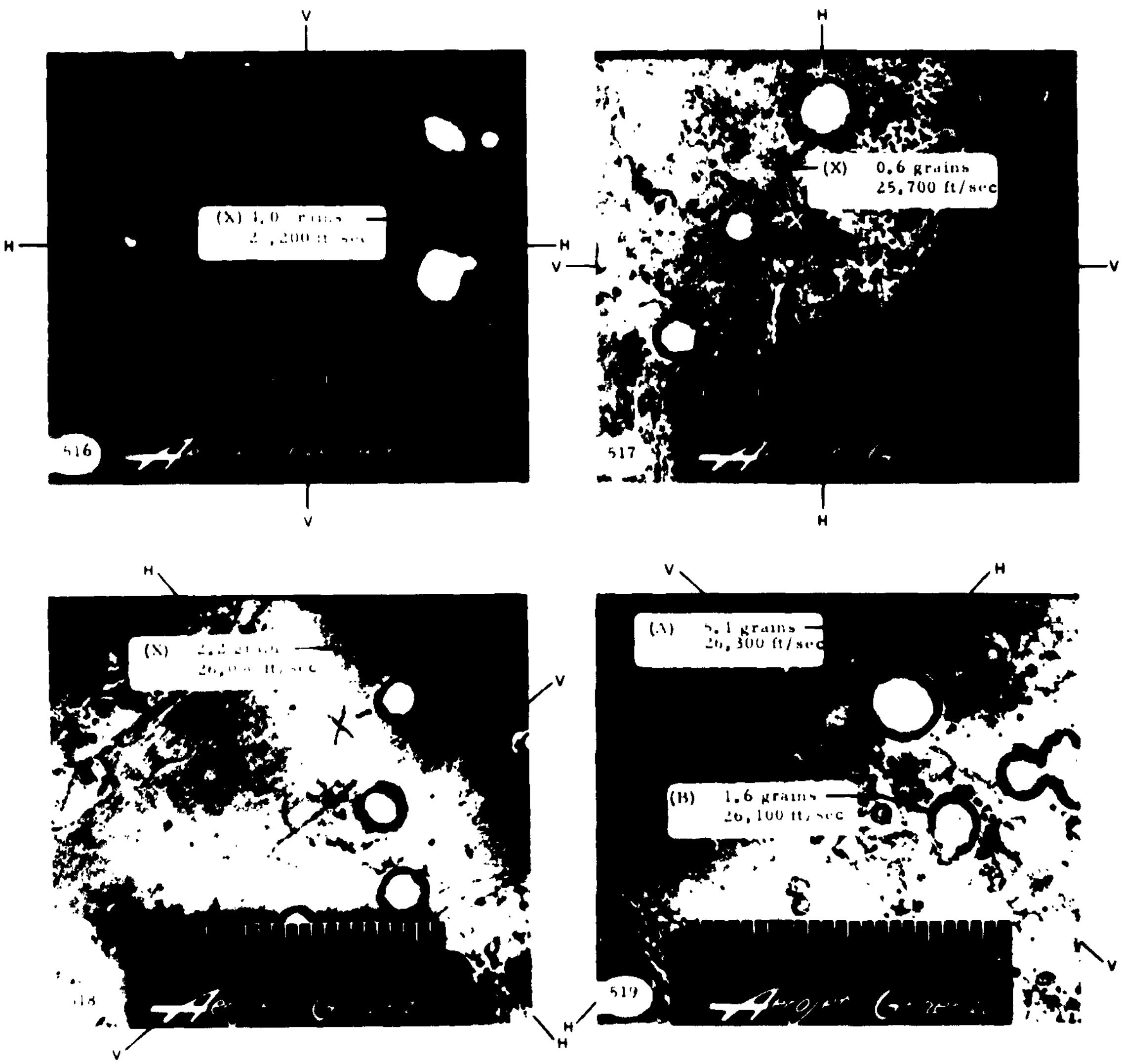


FIGURE 80. TARGET PLATES, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-516, M-517, M-518 AND M-519

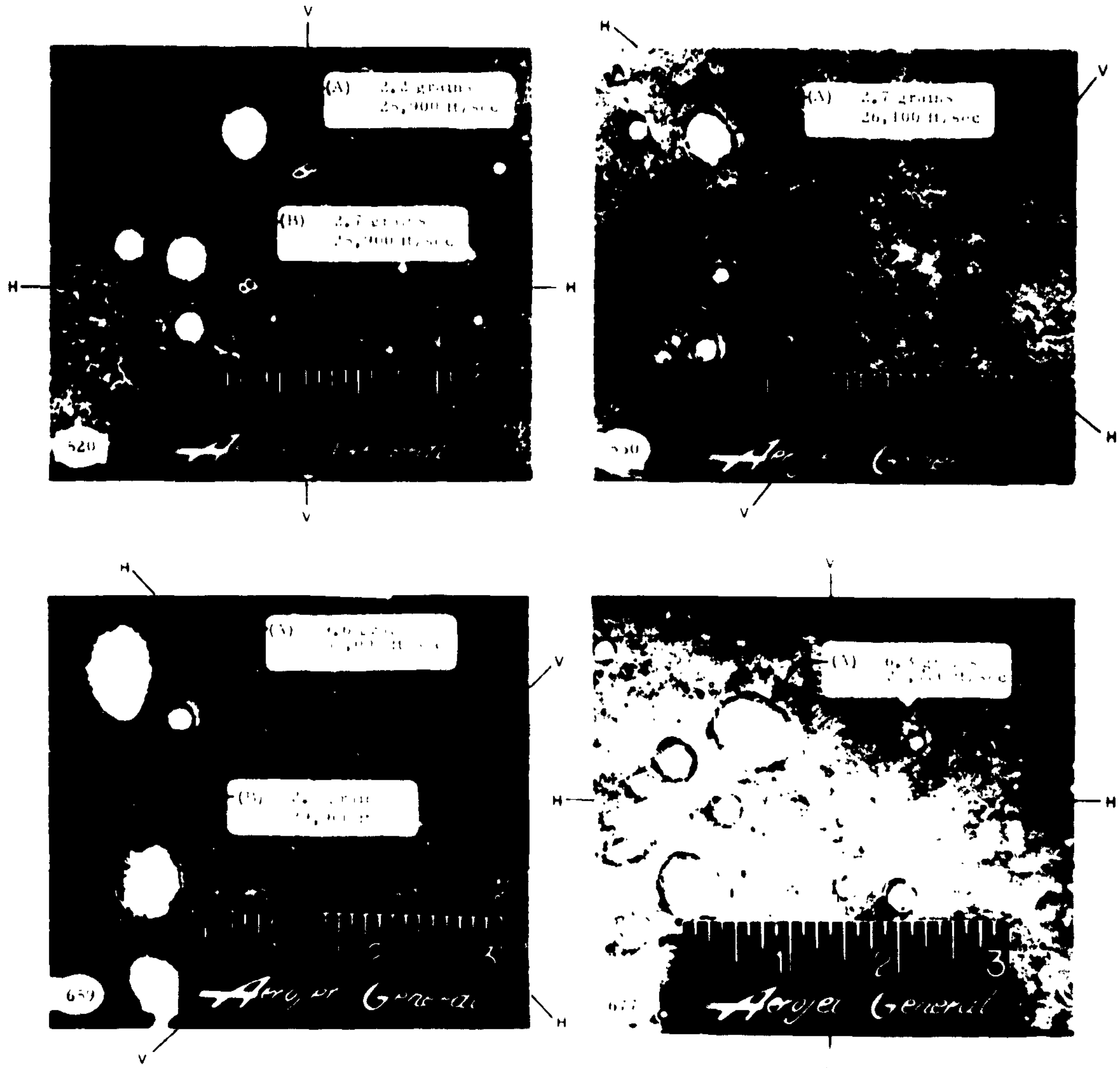


FIGURE 81. TARGET PLATES, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-520, M-530, M-659 AND M-677.

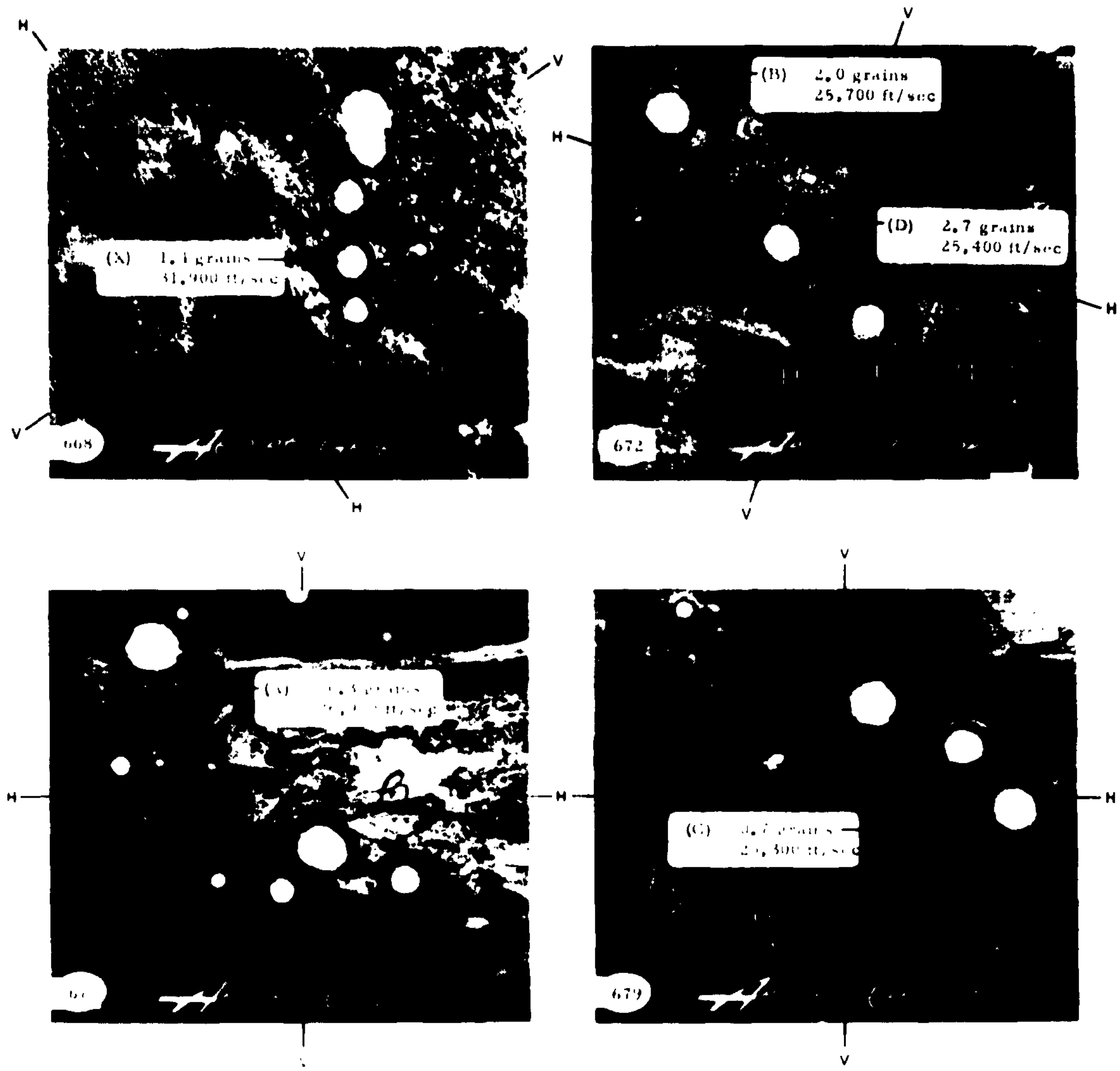


FIGURE 82. TARGET PLATES, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-668, M-672, M-675 AND M-679.

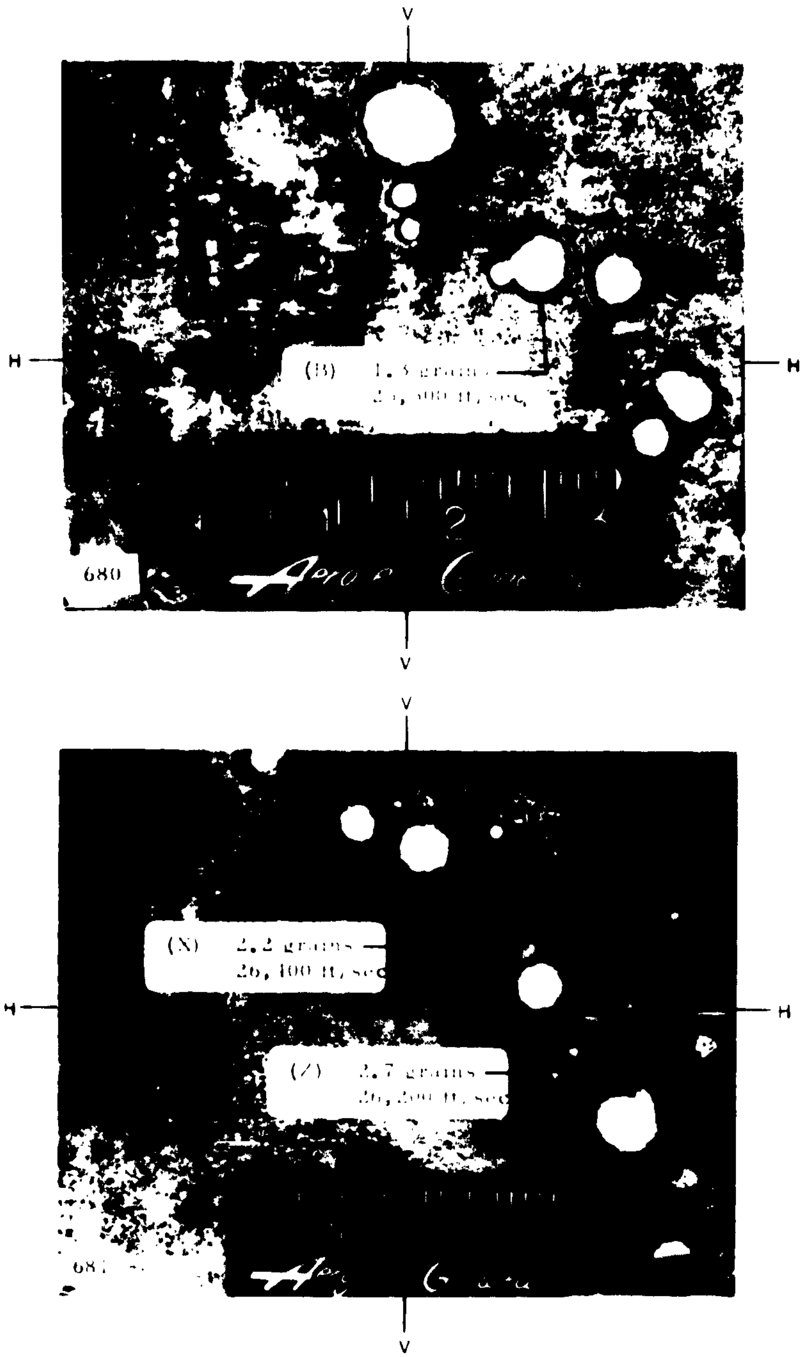


FIGURE 83. TARGET PLATES, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90° OBLIQUITY, TEST NO. M-680 and M-681.

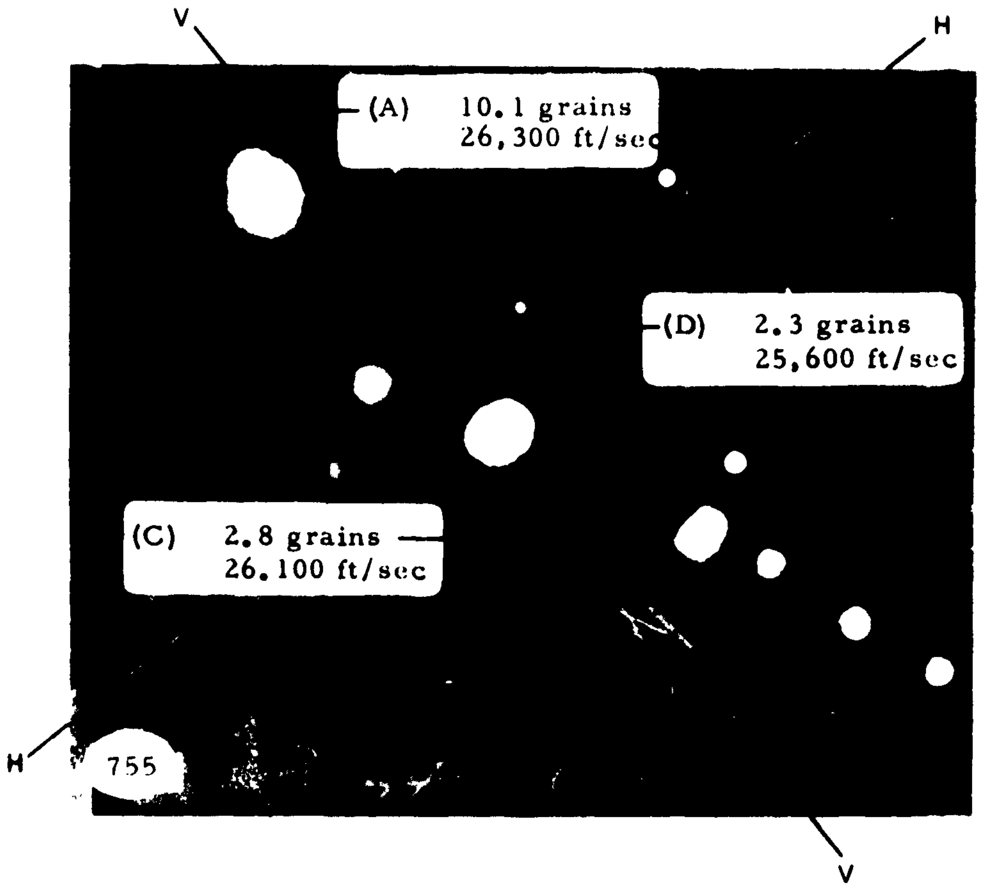
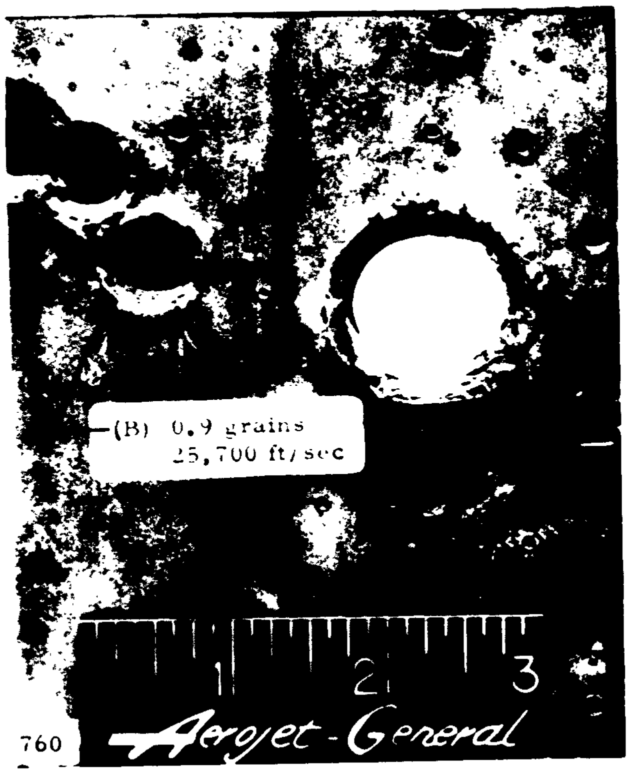


FIGURE 84. TARGET PLATE, 2024-T4 ALUMINUM, 0.100-INCH THICK, 90^{o} OBLIQUITY, TEST NO.M-755.

FIGURE 85. TARGET PLATES, SOFT COPPER, 0.500-INCH THICK, 90° OBLIQUITY, TEST NO. M-756, M-759, M-762 AND M-764.



Front Surface

Back Surface

FIGURE 86. TARGET PLATE, SOFT COPPER 0.500-INCH THICK, 90° OBLIQUITY FRONT AND BACK SURFACE VIEW, TEST No. M-760.

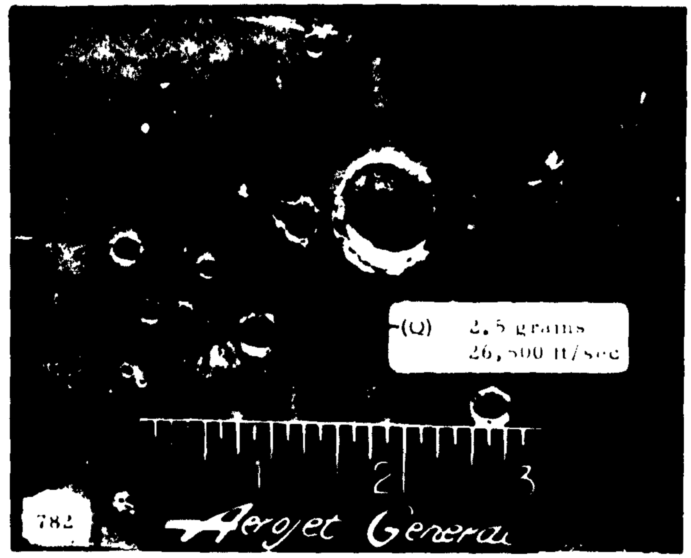


FIGURE 87. TARGET PLATE, SOFT COPPER, 0.500-INCH THICK, 90° OBLIQUITY TEST NO. M-782.

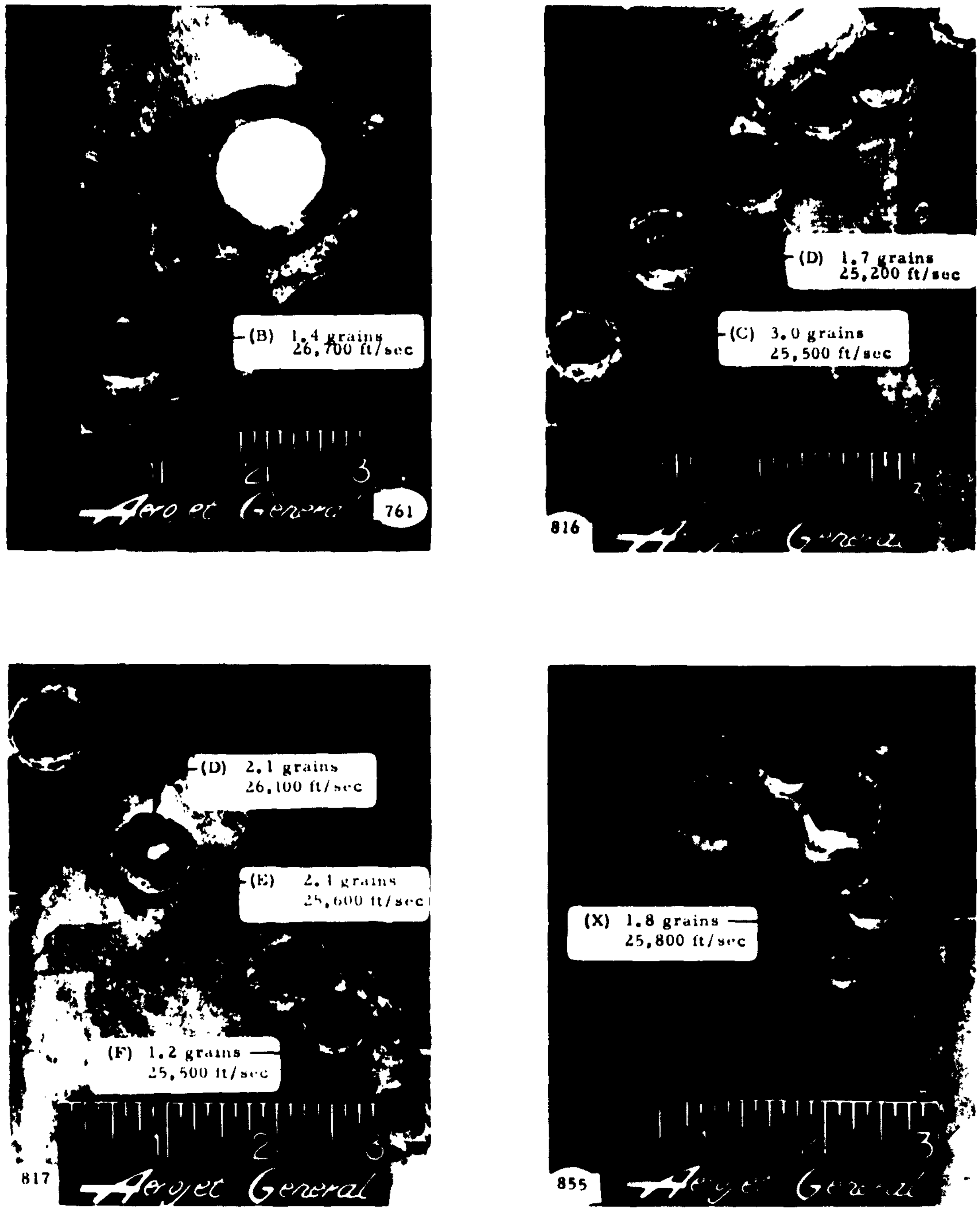
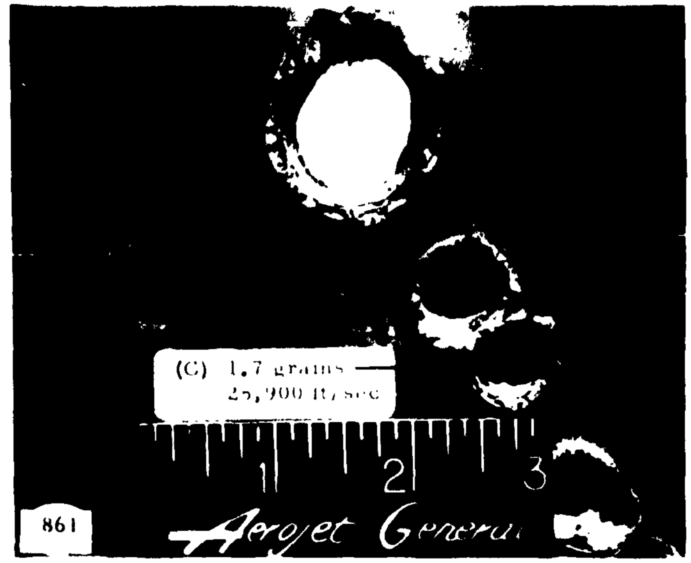


FIGURE 88. TARGET PLATES, SOFT COPPER, 0.500-INCH THICK, 90° OBLIQUITY TEST NO. M-761, M-861, M-817 AND M-855.



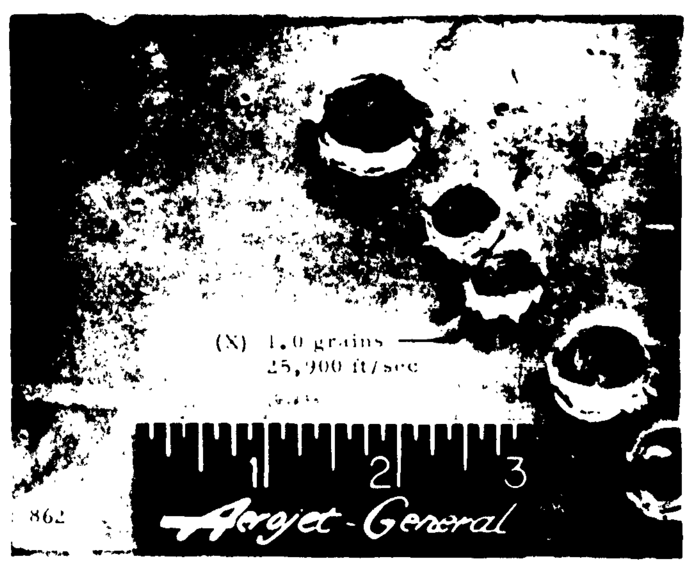
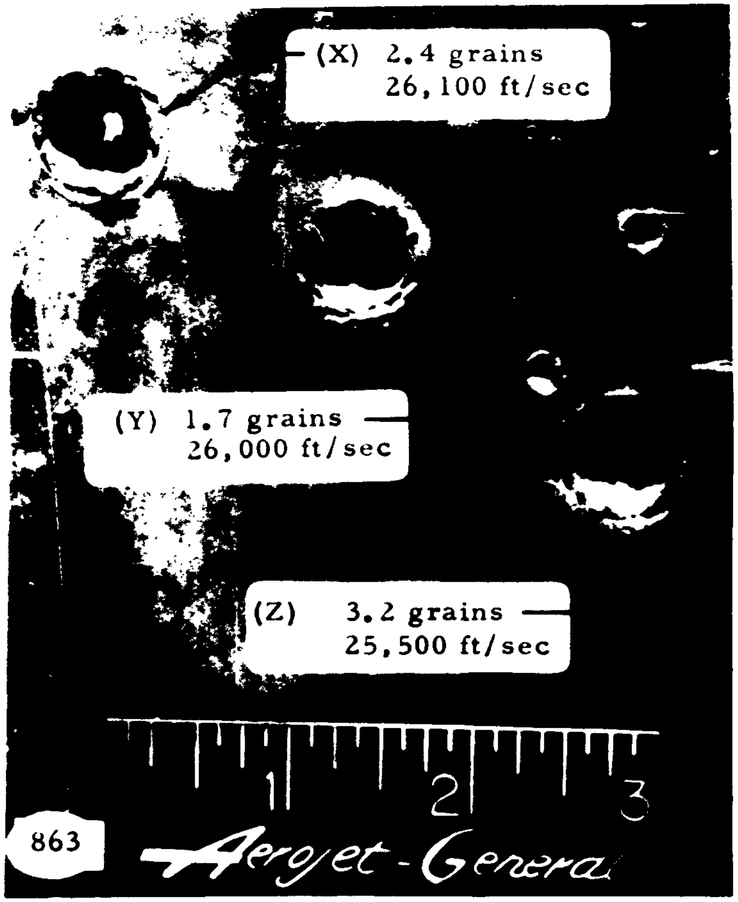


FIGURE 89. TARGET PLATES, SOFT COPPER, 0.500-INCH THICK, 90° OBLIQUITY TEST NO. M-861 and M-862.



Front Surface

Back Surface

FIGURE 90. TARGET PLATE, SOFT COPPER, 0.500-INCH THICK, 90° OBLIQUITY FRONT AND BACK SURFACE VIEWS TEST NO. M-863.

FIGURE 91-TARGET HOLE AREA VS PROJECTILE MASS

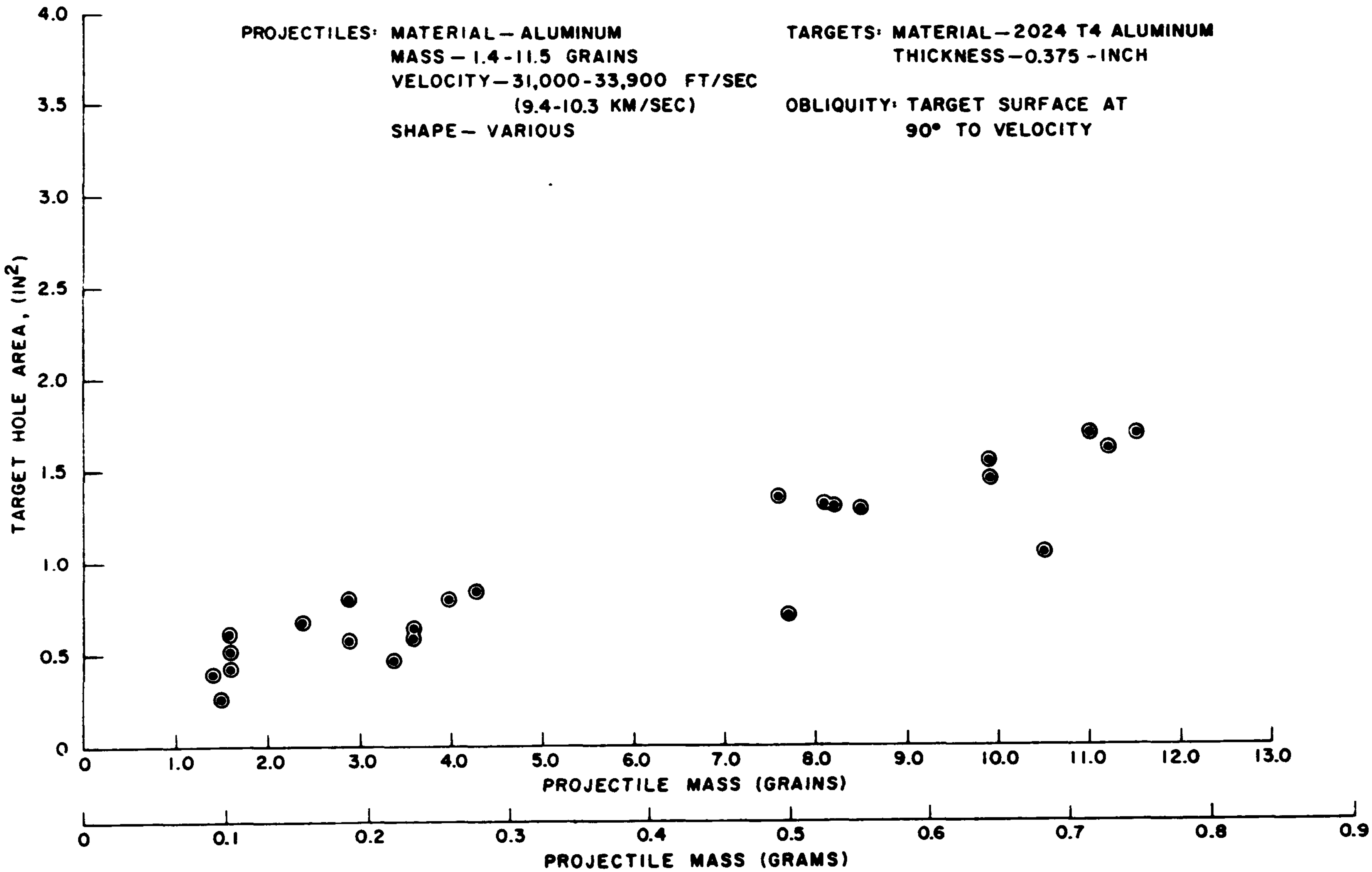


FIGURE 92-TARGET HOLE AREA VS PROJECTILE MASS

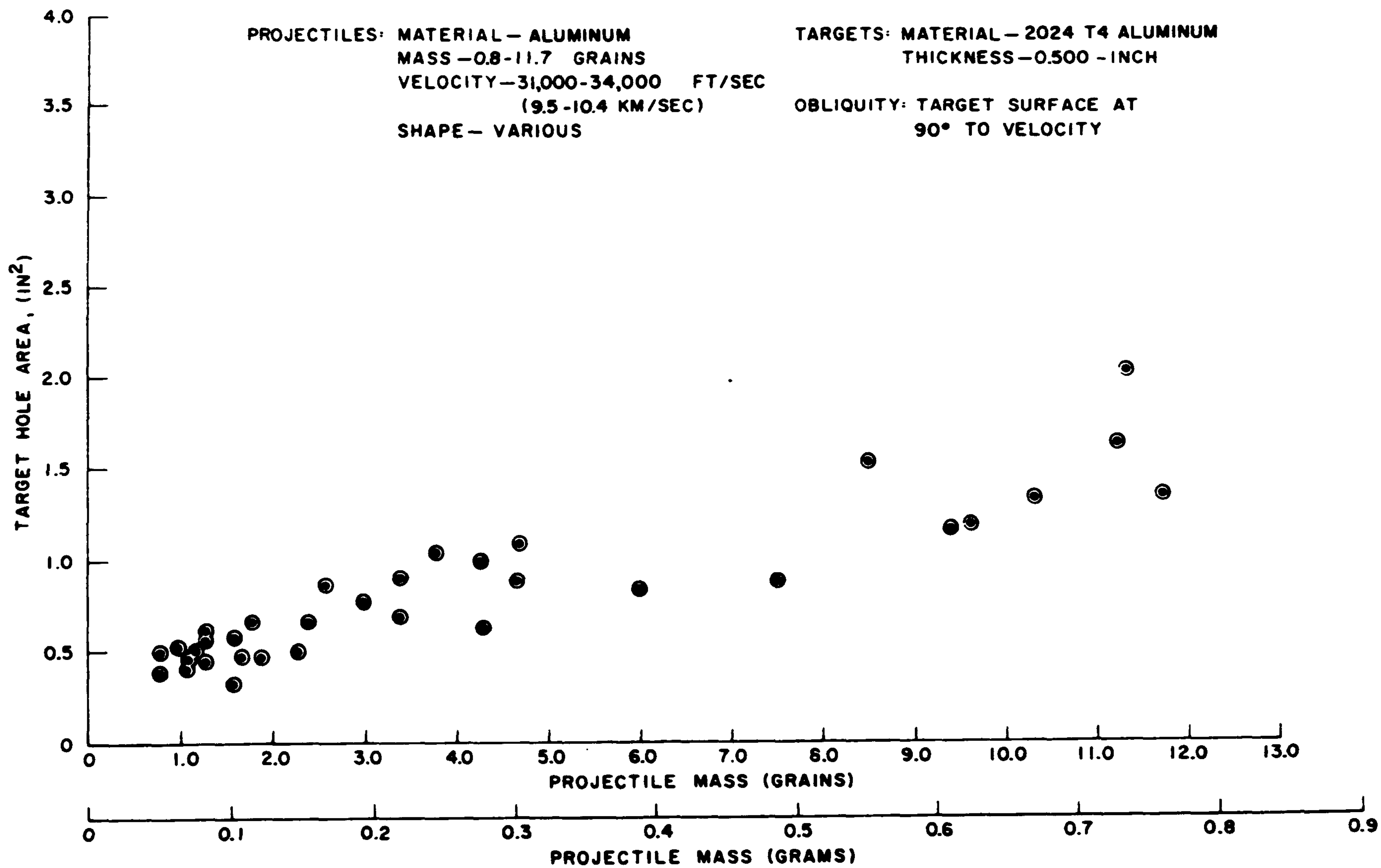


FIGURE 93-TARGET HOLE AREA VS PROJECTILE MASS

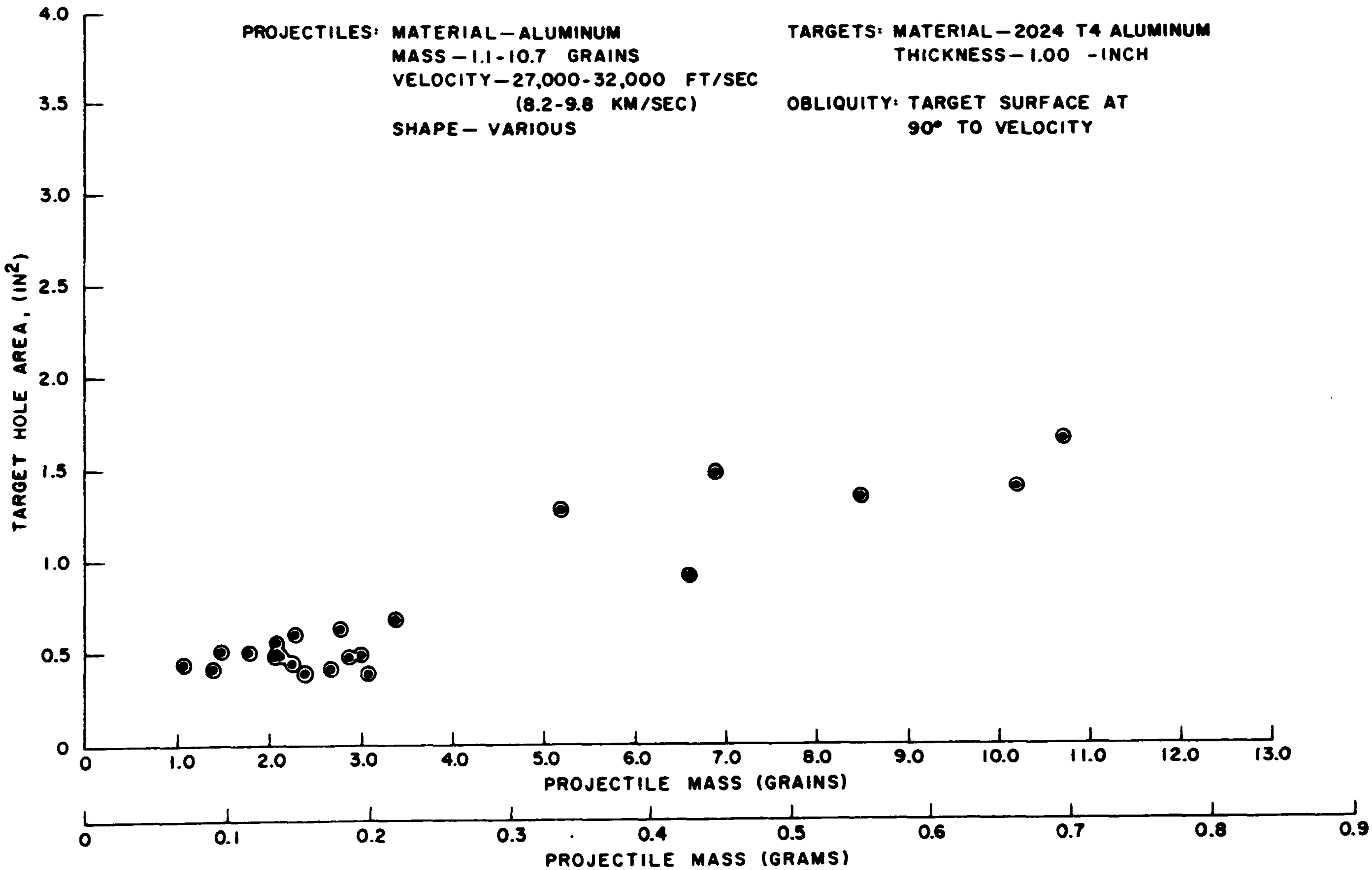
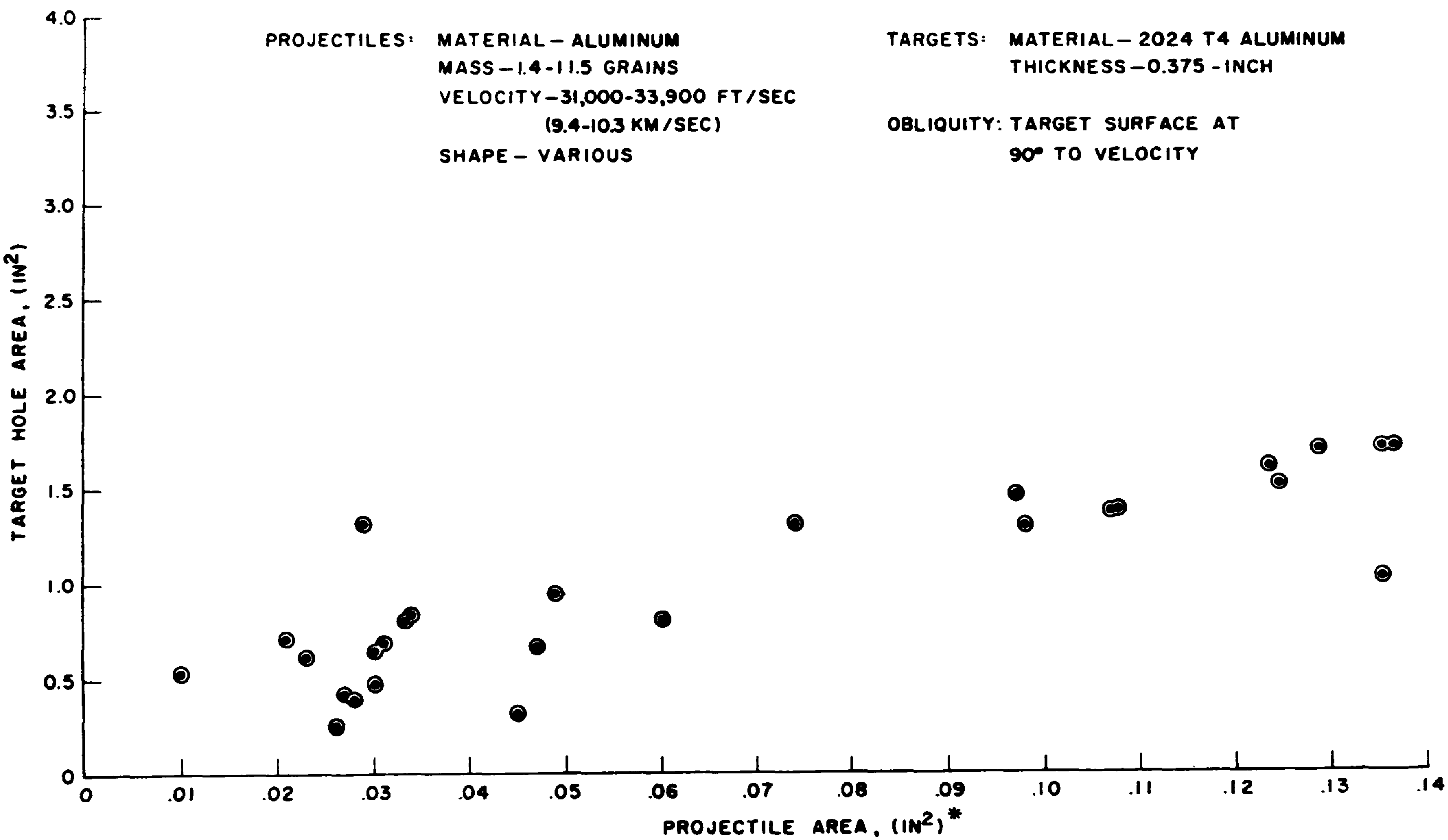
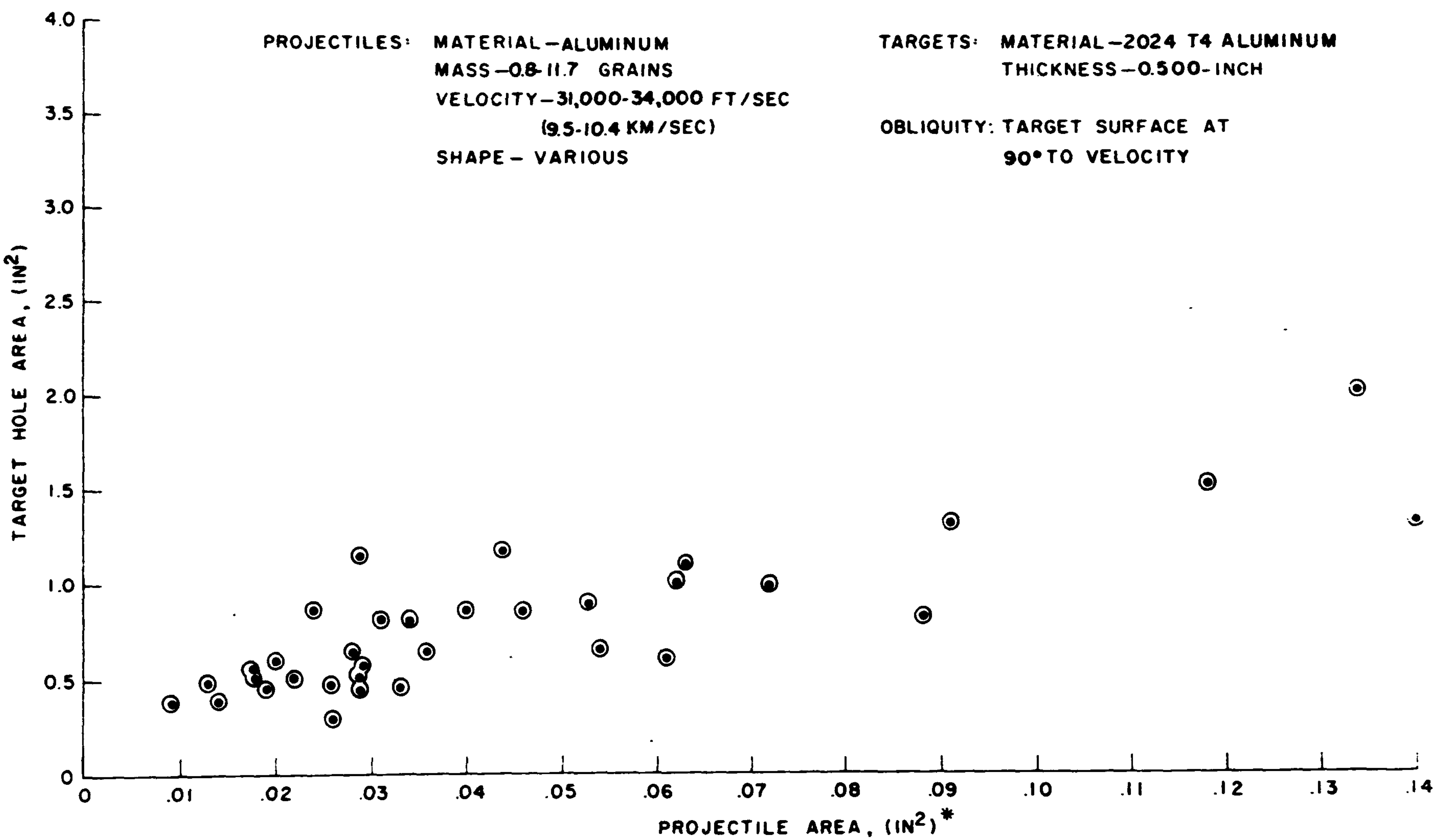


FIGURE 94 -TARGET HOLE AREA VS PROJECTILE AREA*



*ON PLANE NORMAL TO VELOCITY

FIGURE 95 - TARGET HOLE AREA VS PROJECTILE AREA*



*ON PLANE NORMAL TO VELOCITY

FIGURE 96. SECTIONED VIEW OF TARGET PLATE FROM TEST NO. 706, 2024-T4 ALUMINUM, 1.00-INCH THICK, 90° OBLIQUITY.

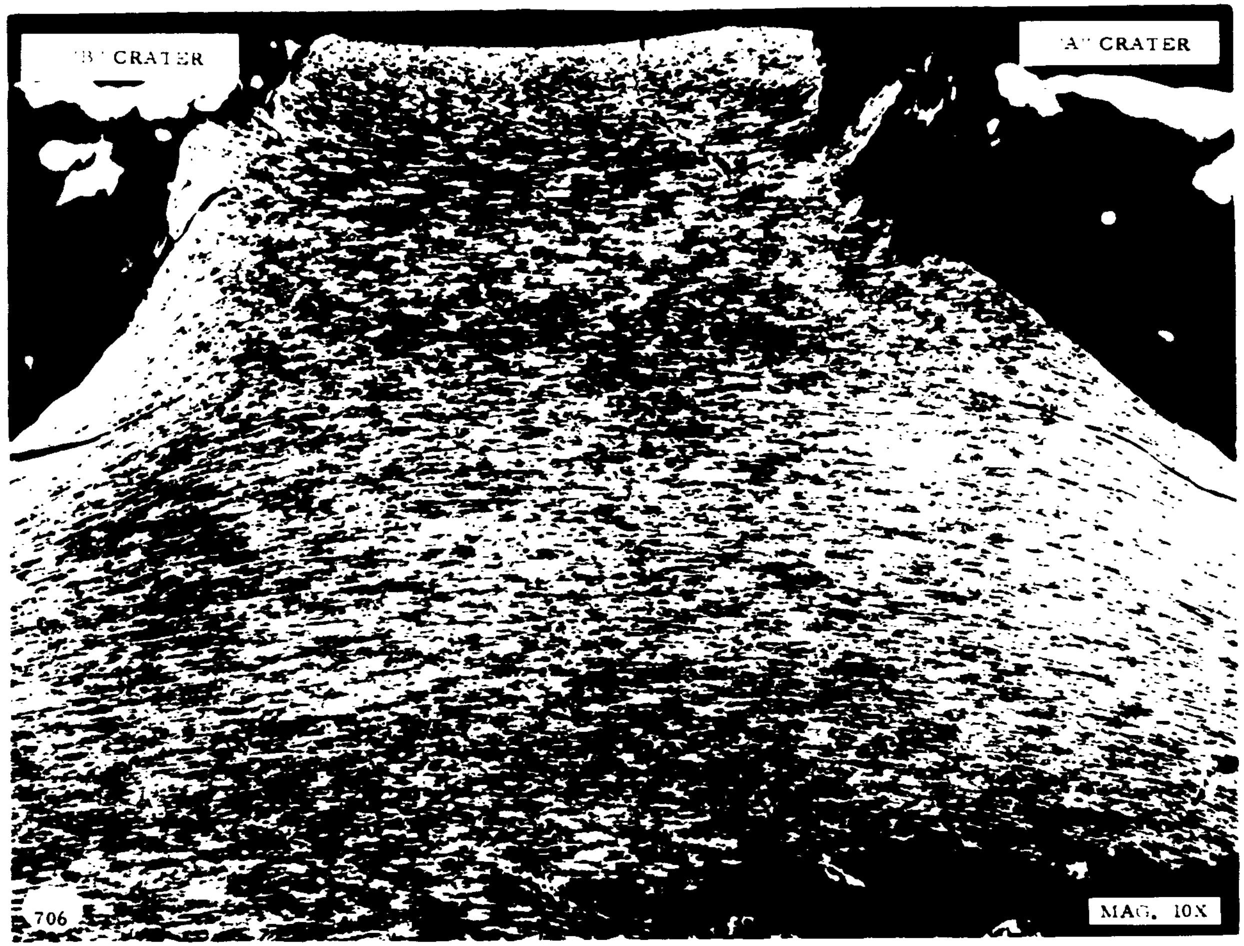


FIGURE 97. 10 X MAGNIFICATION OF SECTION OF TARGET PLATE FROM TEST NO. 706, 2024-T4 ALUMINUM, 1.00 INCH THICK, 90° OBLIQUITY.

FIGURE 98 -TARGET HOLE AREA VS PROJECTILE MASS

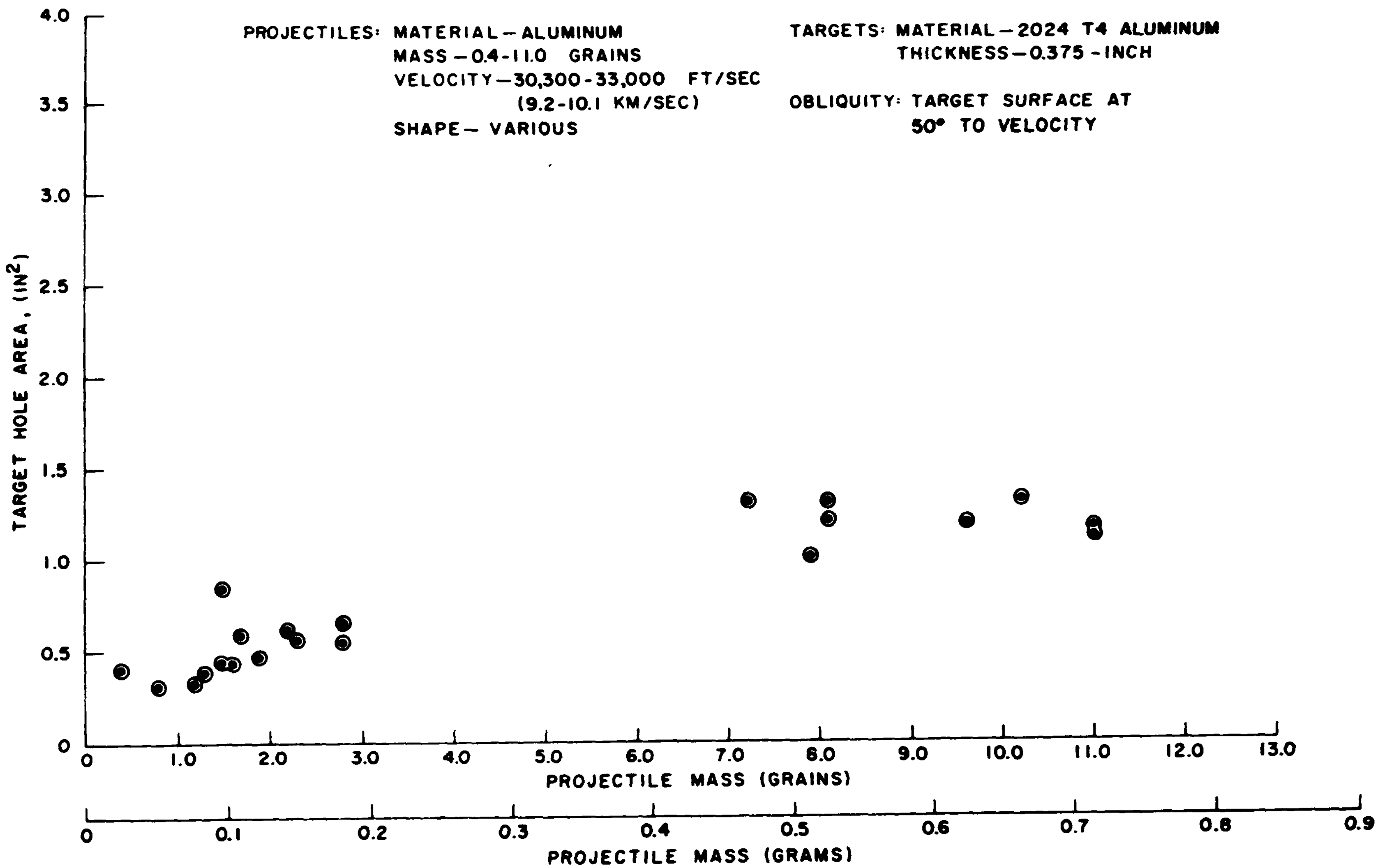


FIGURE 99 -TARGET HOLE AREA VS PROJECTILE MASS

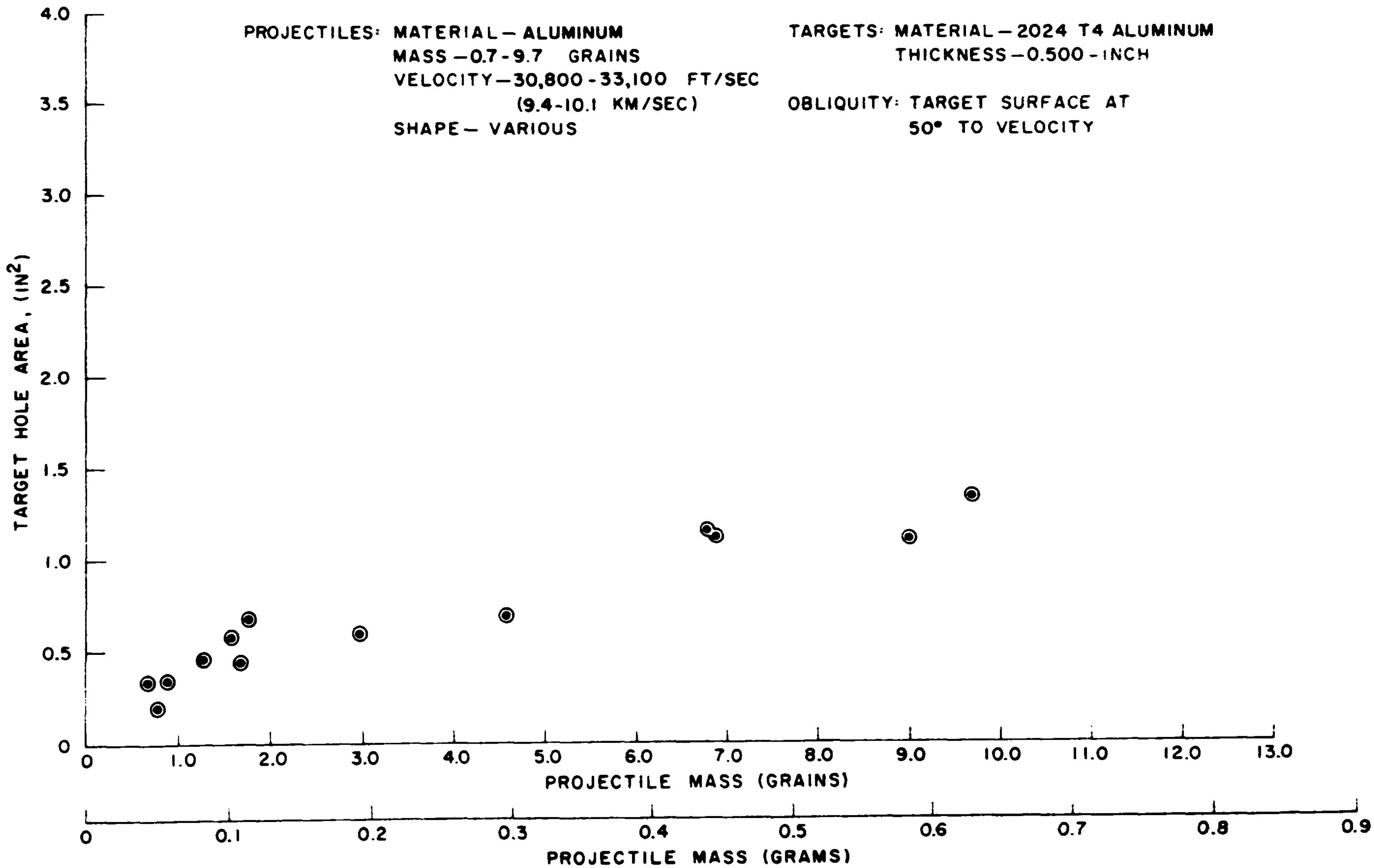


FIGURE 100-TARGET HOLE AREA VS PROJECTILE MASS

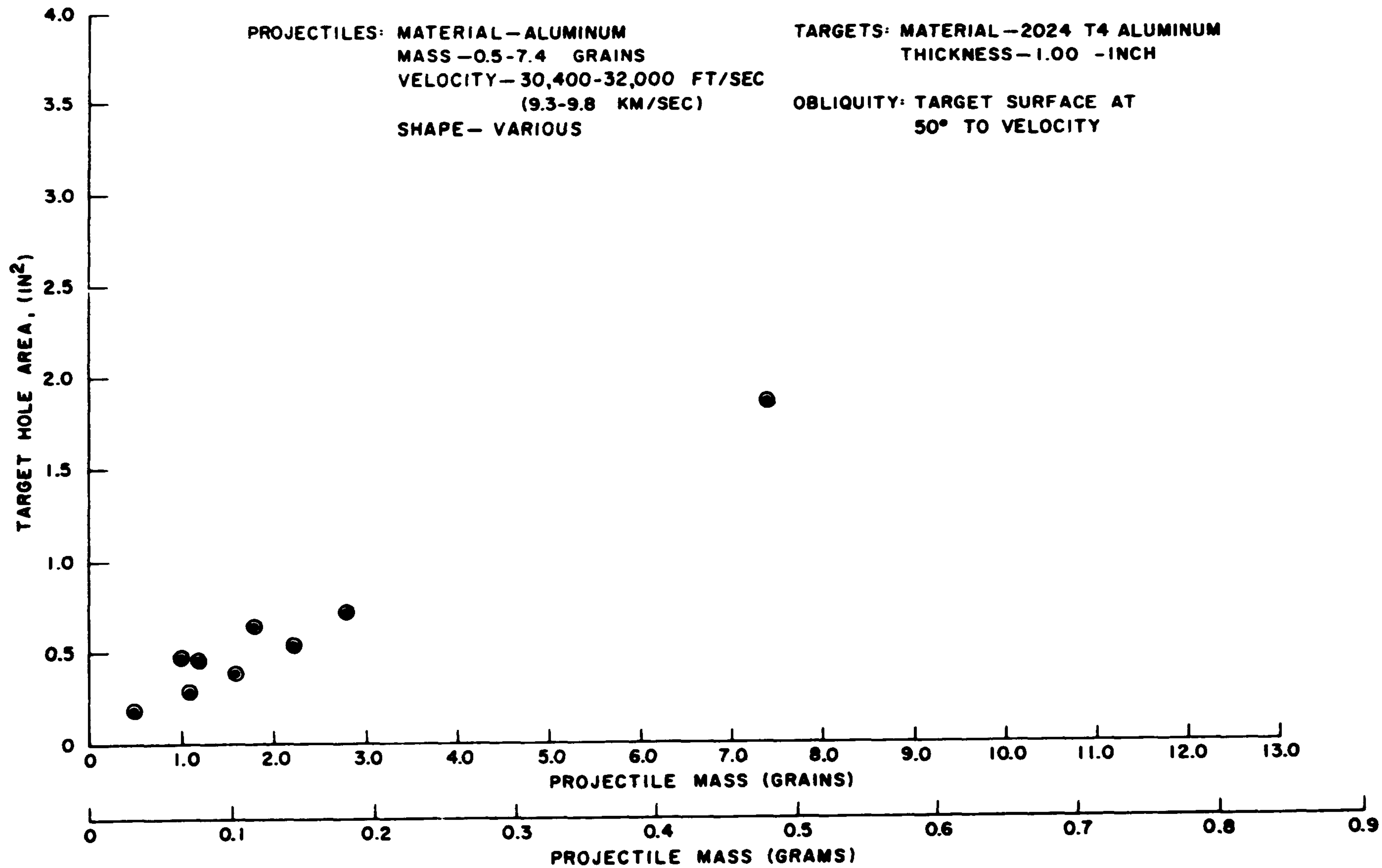


FIGURE 101-TARGET HOLE AREA VS PROJECTILE MASS

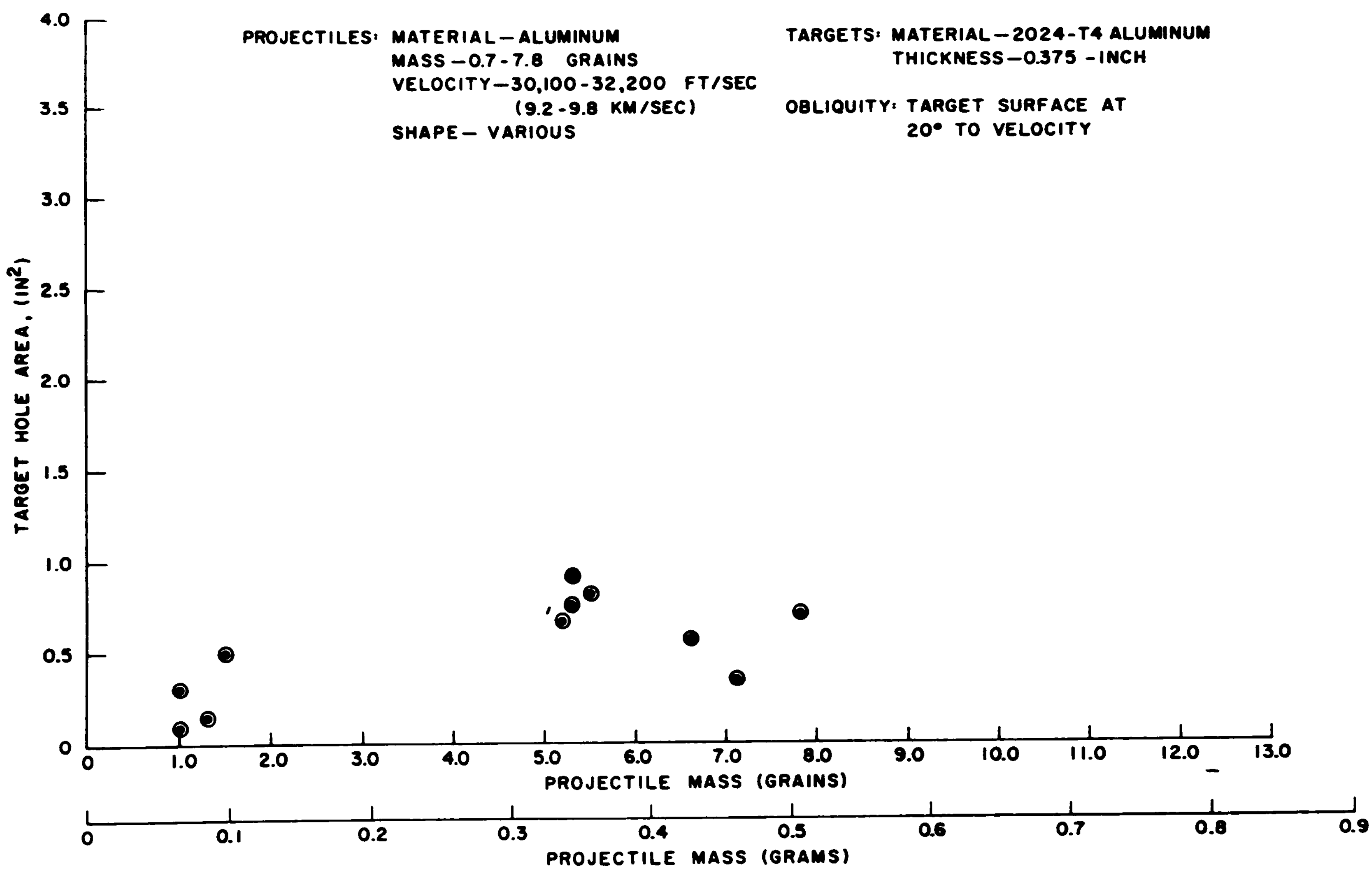


FIGURE 102 - TARGET HOLE AREA VS PROJECTILE MASS

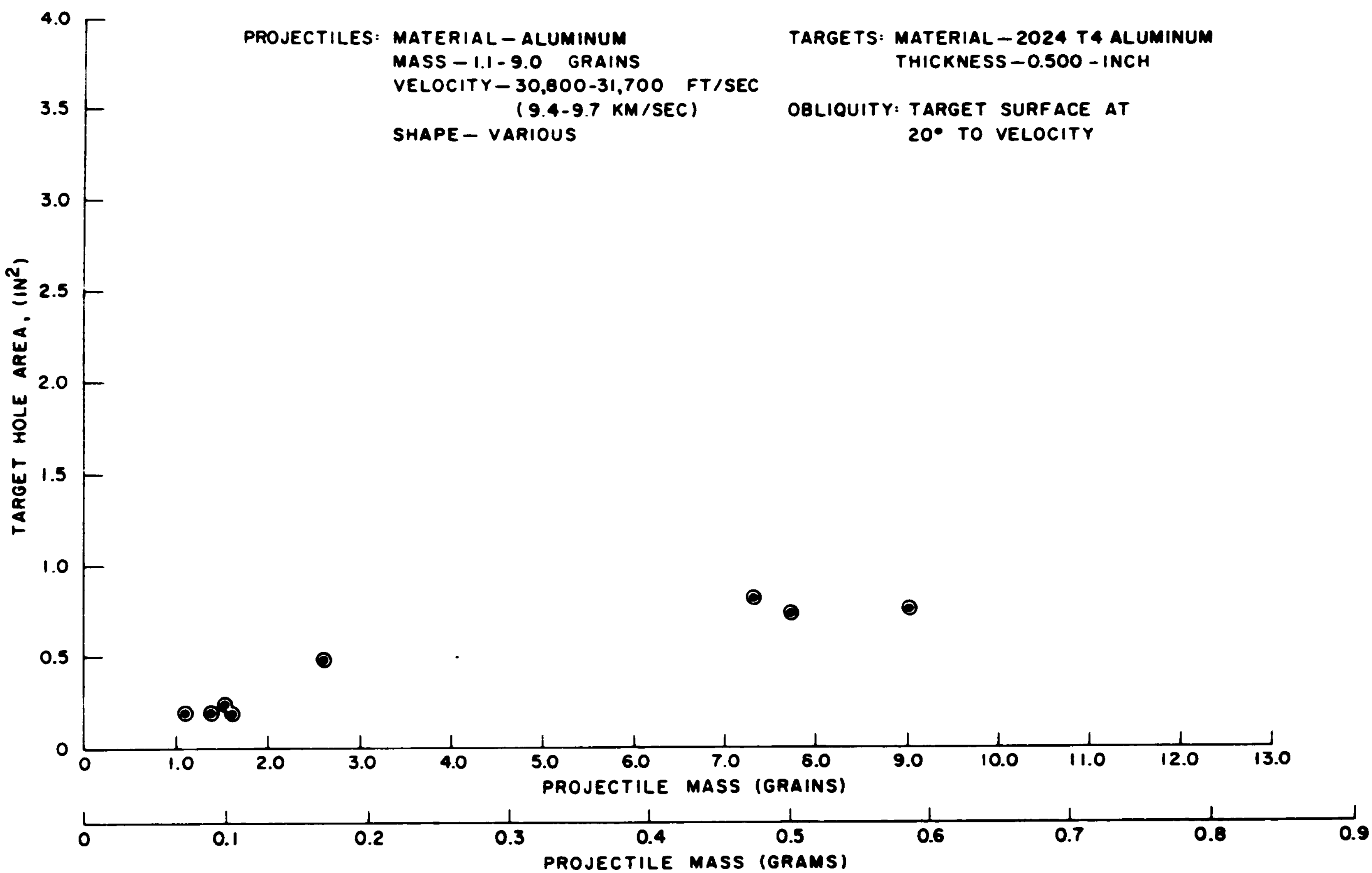


FIGURE 103 - TARGET HOLE AREA VS PROJECTILE MASS

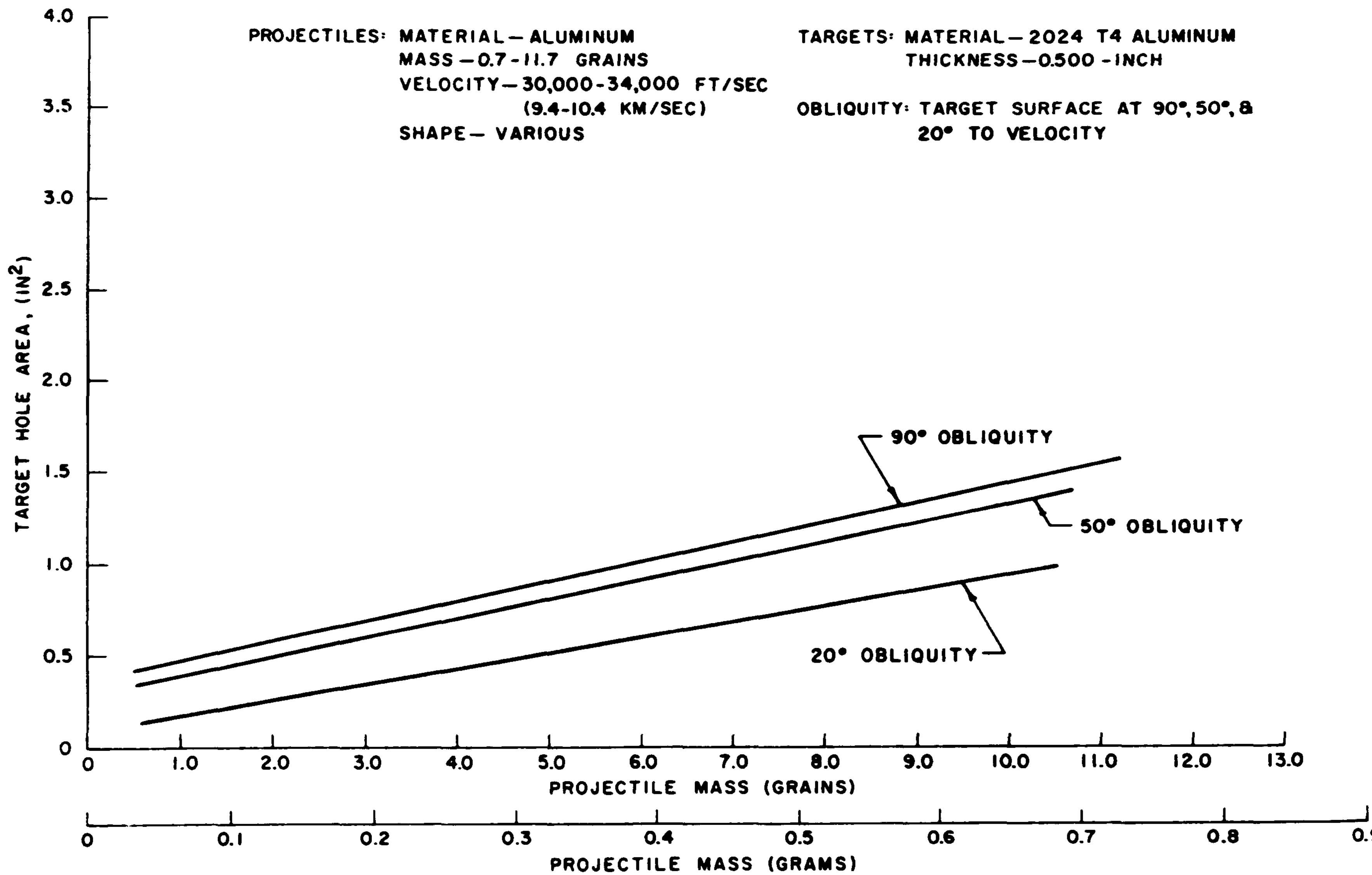


FIGURE 104 - CRATER VOLUME VS PROJECTILE ENERGY

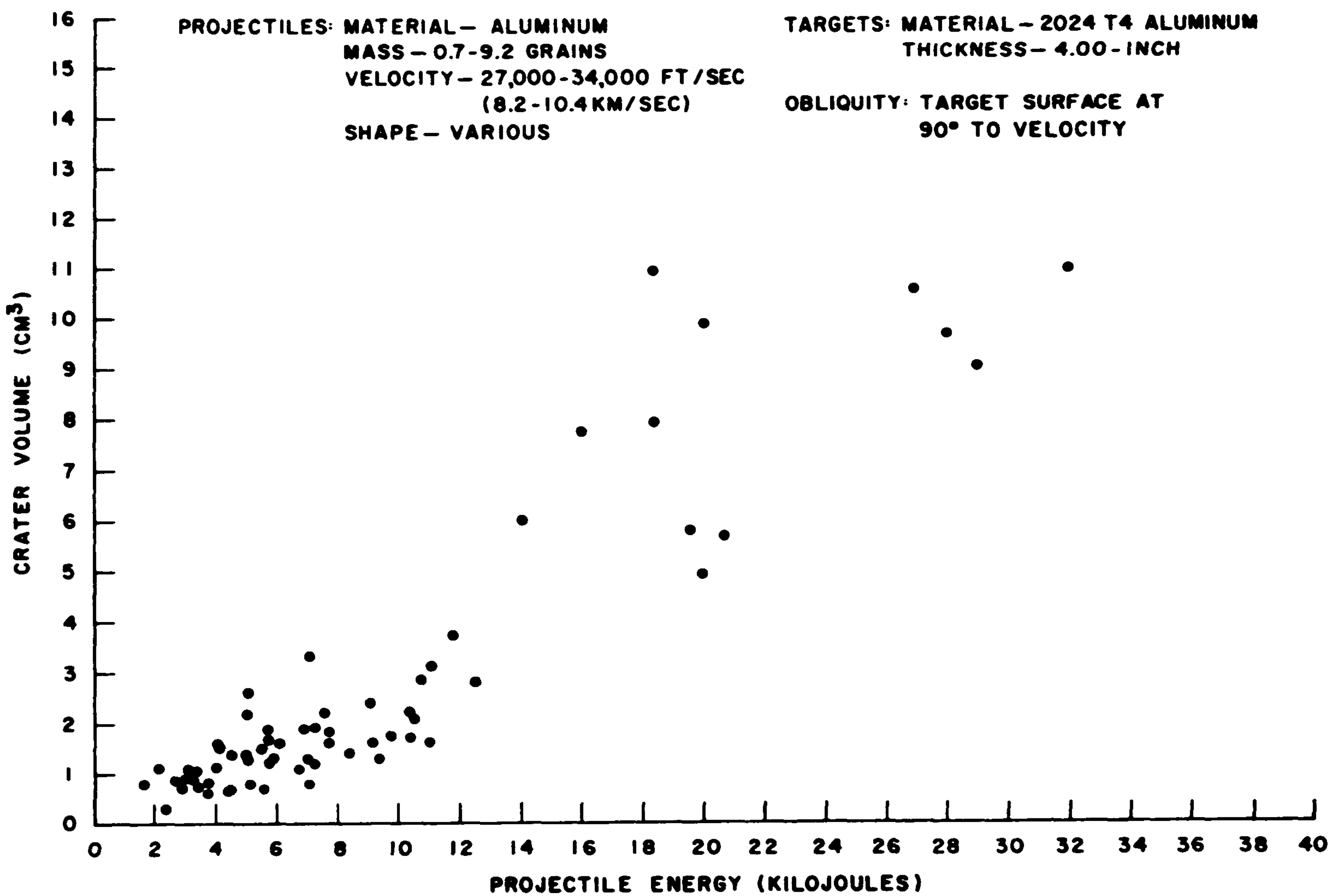
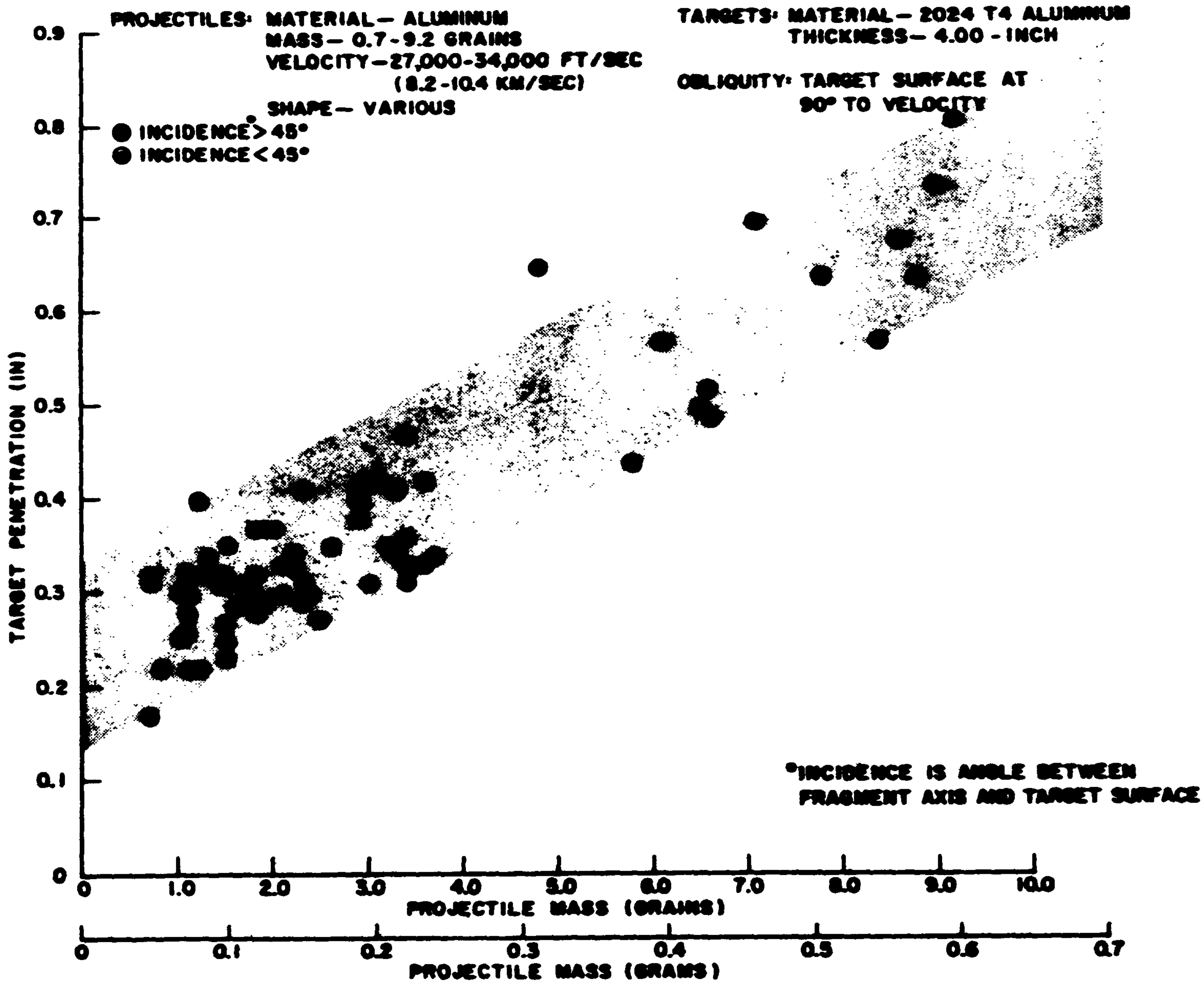


FIGURE 105 -TARGET PENETRATION VS PROJECTILE MASS



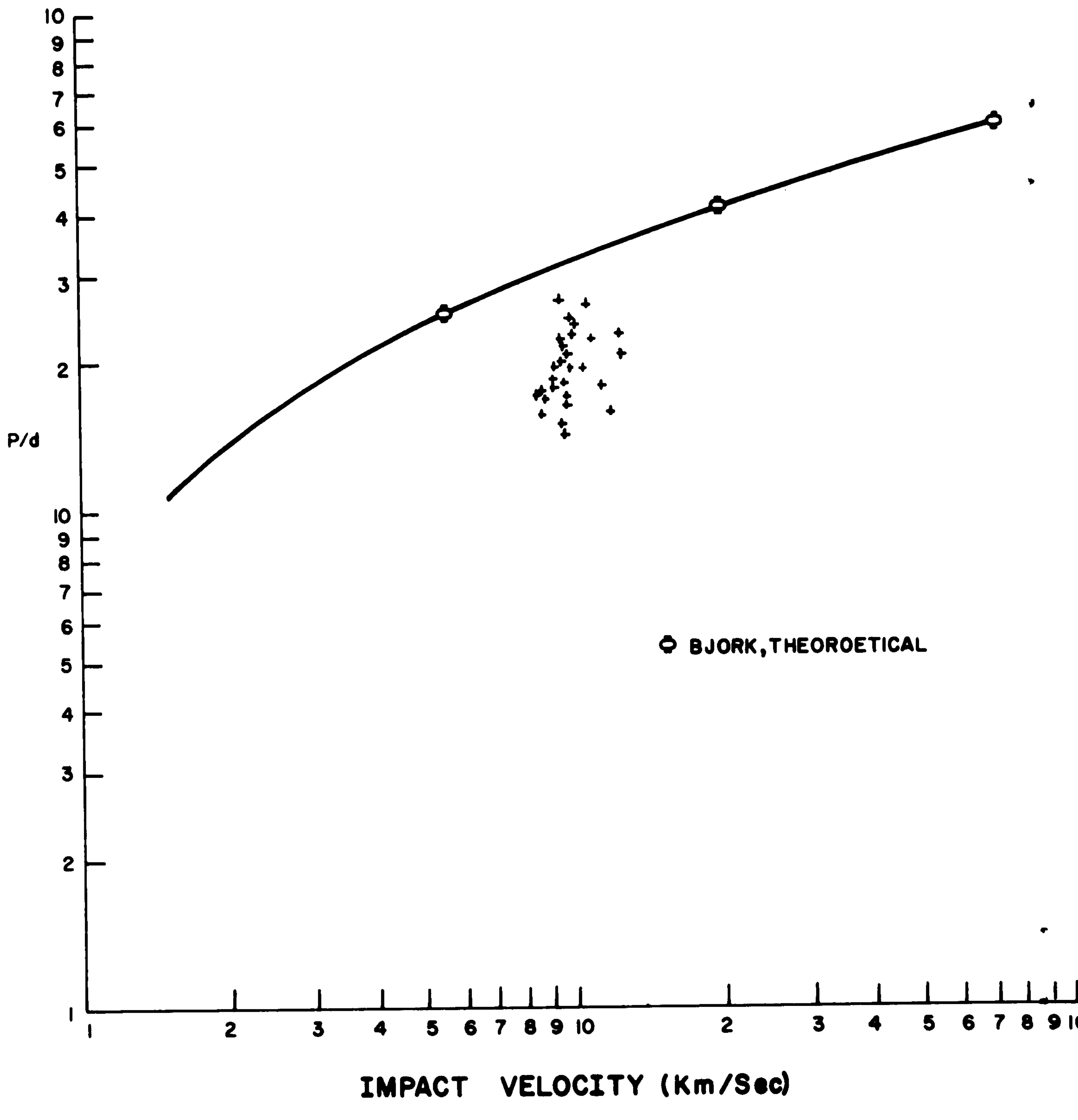


Figure 106. Penetration/projectile diameter versus velocity, aluminum impacts on 2024-T4 aluminum targets.

FIGURE 107-TARGET HOLE AREA VS PROJECTILE MASS

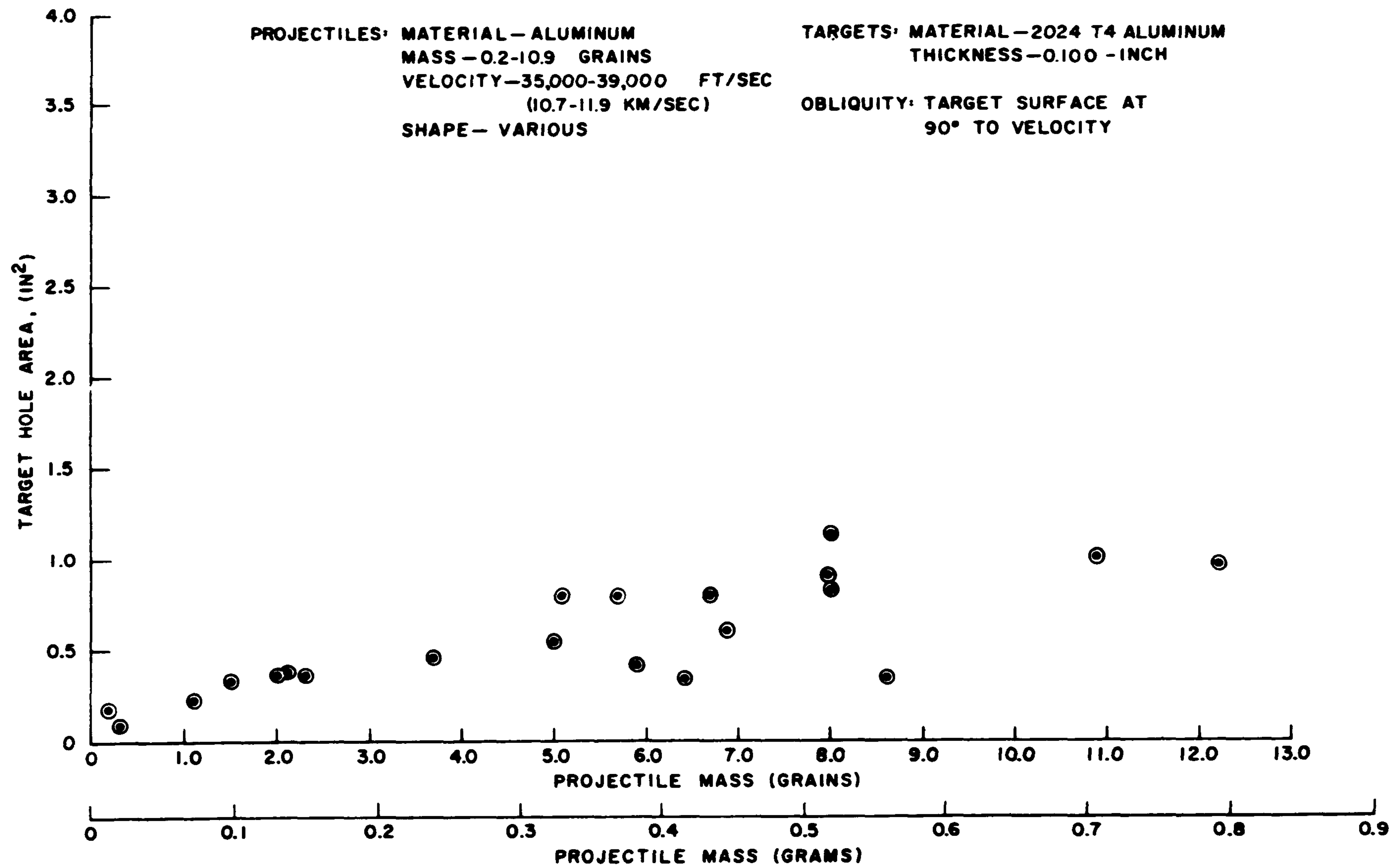
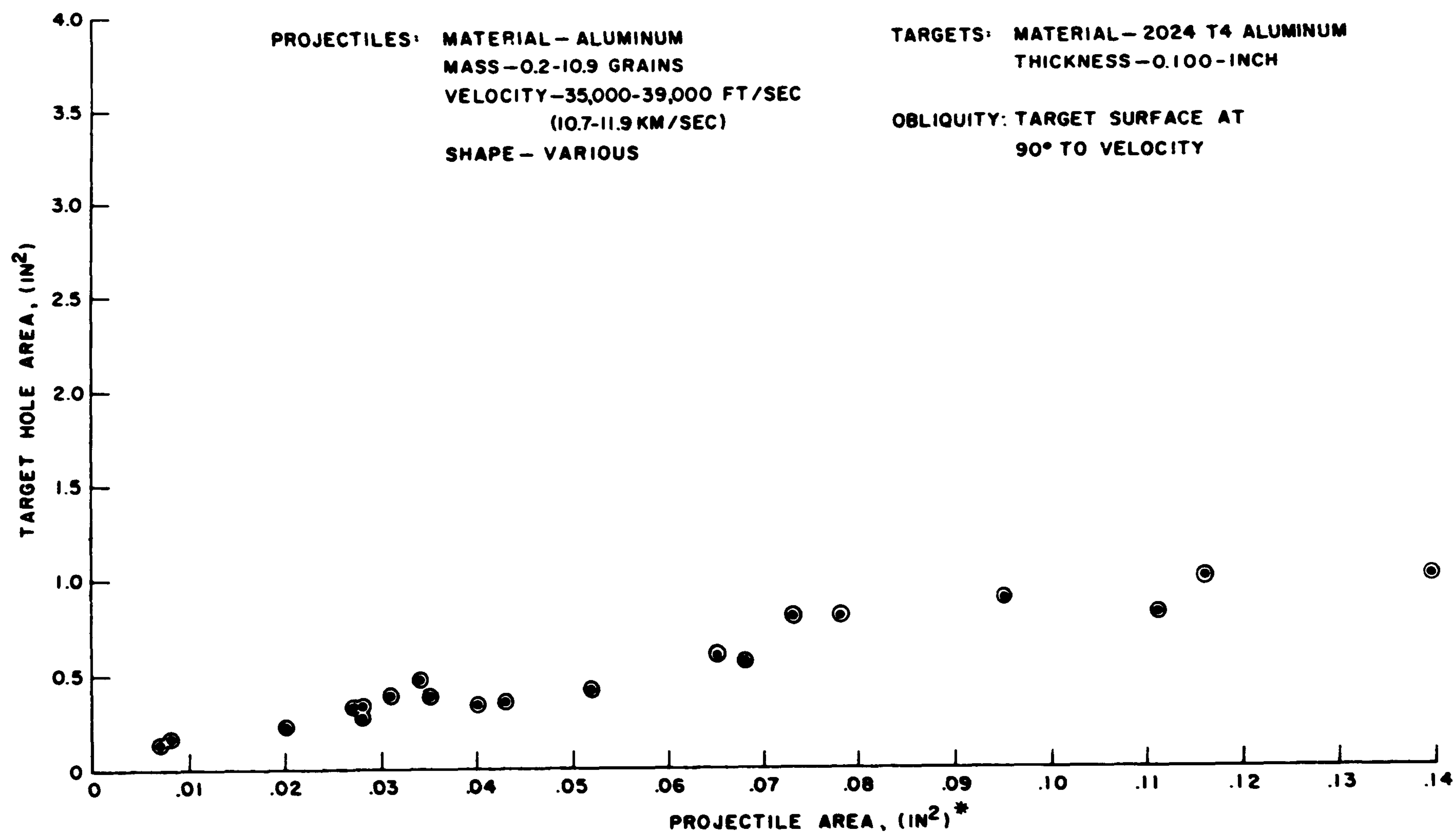
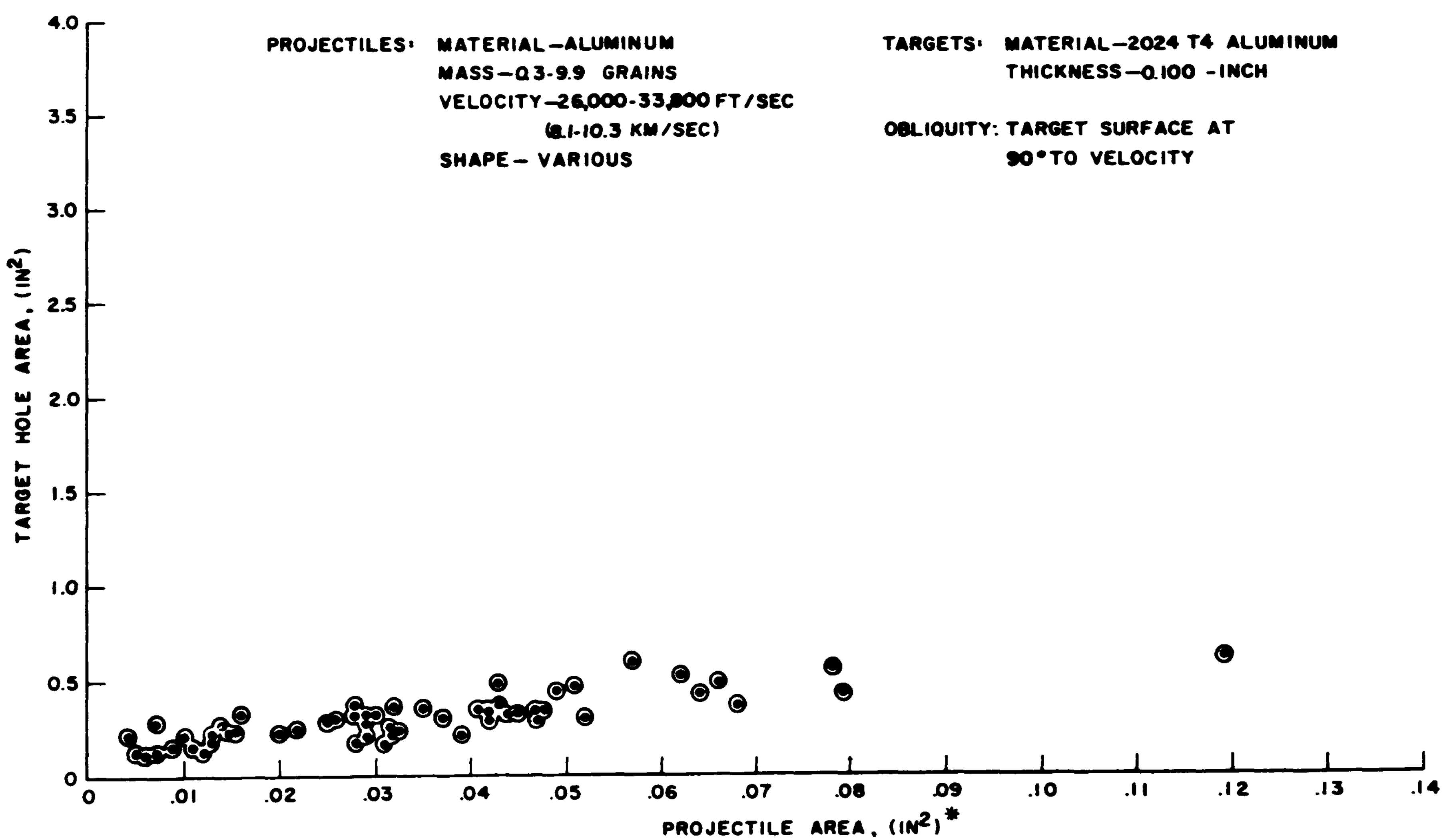


FIGURE 108-TARGET HOLE AREA VS PROJECTILE AREA*



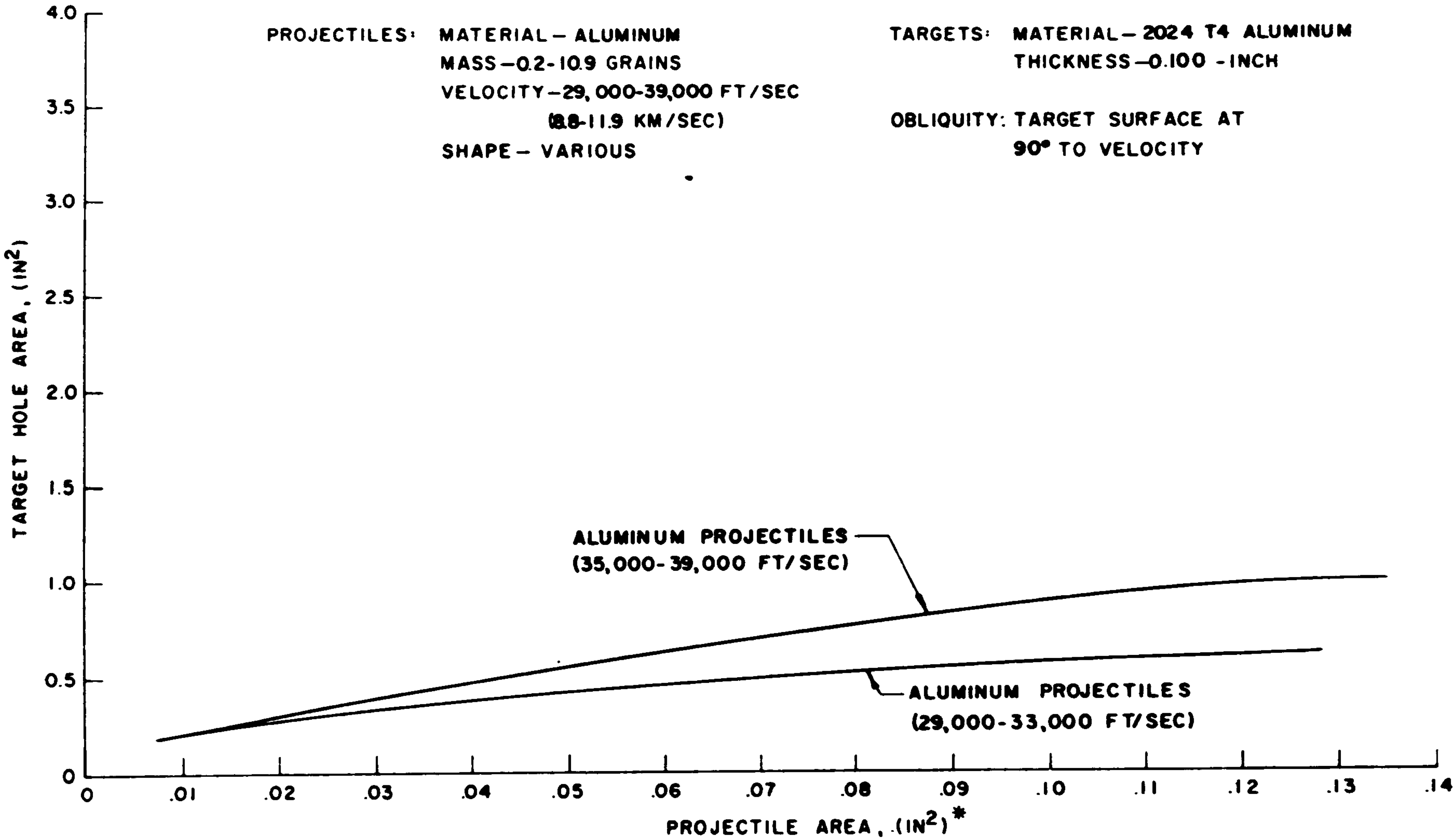
*ON PLANE NORMAL TO VELOCITY

FIGURE 109-TARGET HOLE AREA VS PROJECTILE AREA*



*ON PLANE NORMAL TO VELOCITY

FIGURE 110-TARGET HOLE AREA VS PROJECTILE AREA*



*ON PLANE NORMAL TO VELOCITY

FIGURE III-TARGET HOLE AREA VS PROJECTILE MASS

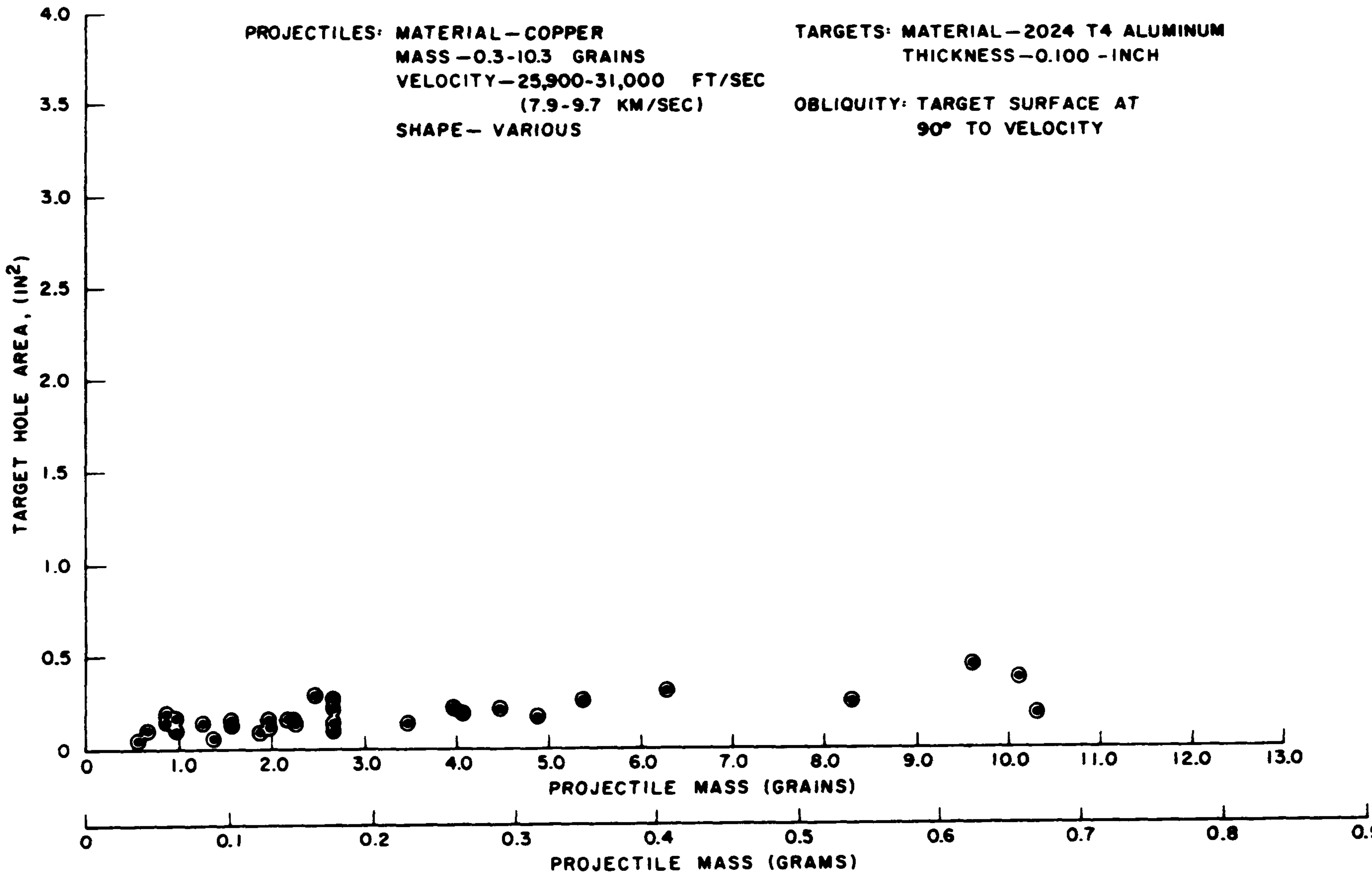
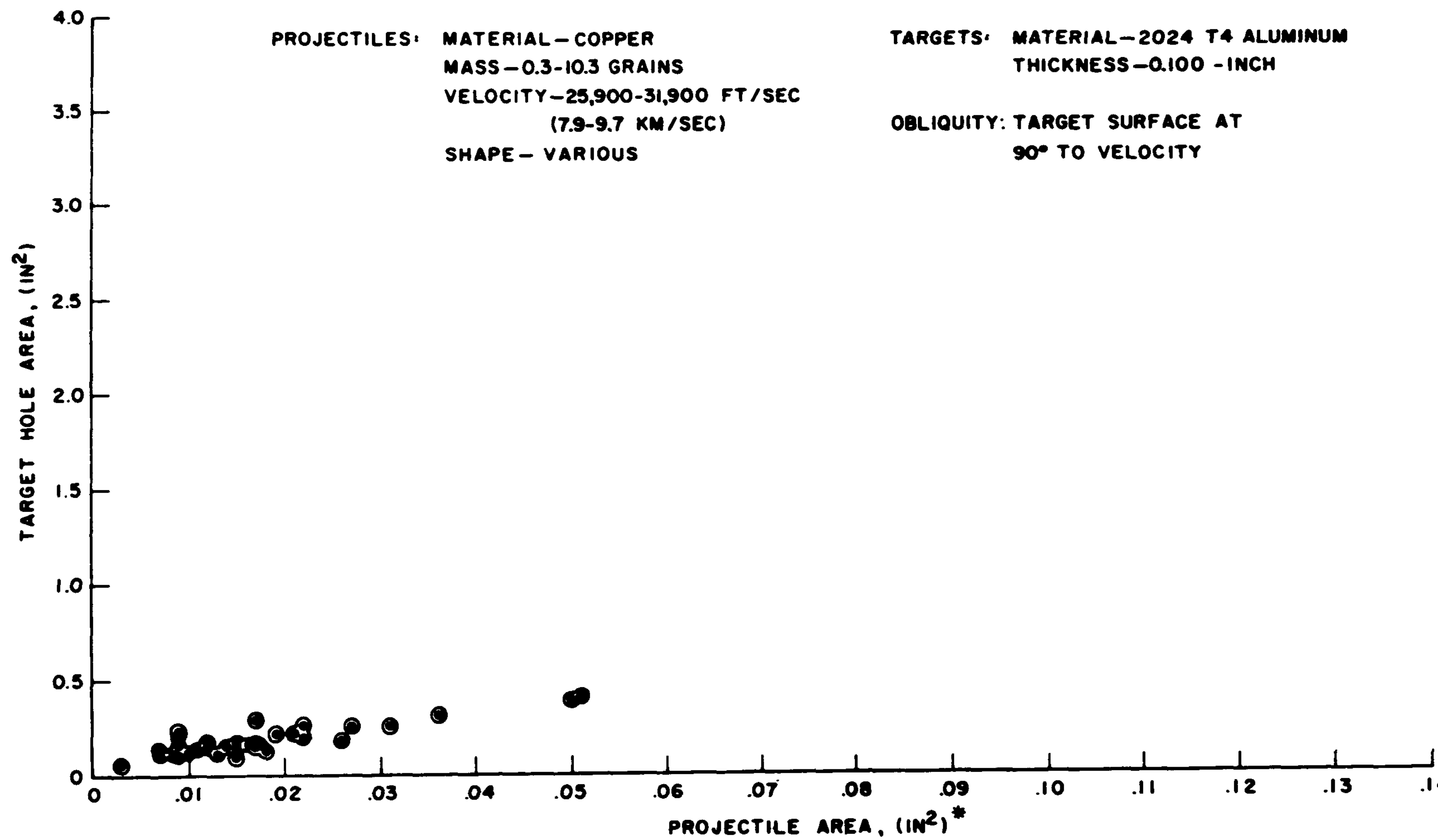
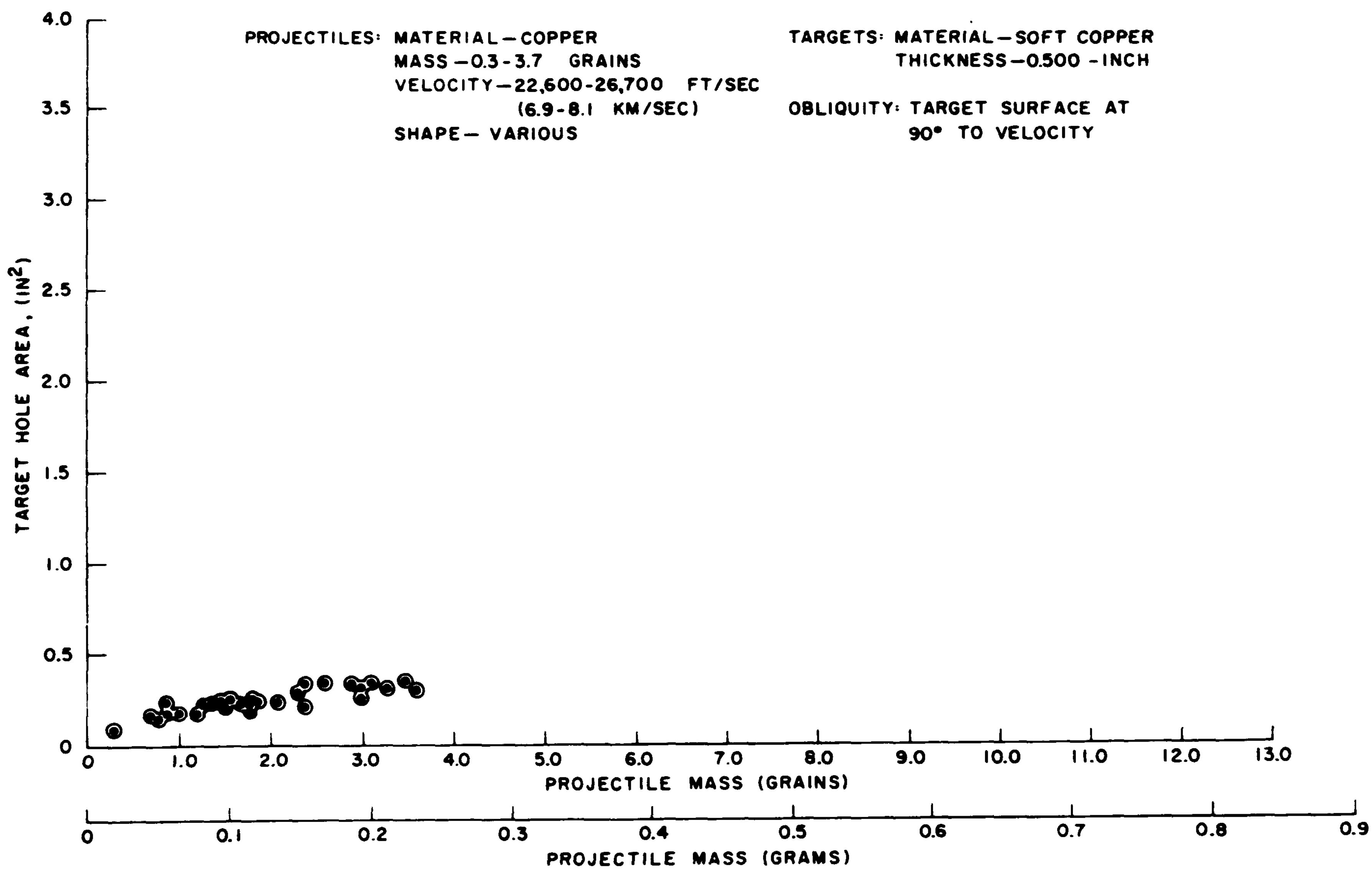


FIGURE 112-TARGET HOLE AREA VS PROJECTILE AREA*



*ON PLANE NORMAL TO VELOCITY

FIGURE 113 - TARGET HOLE AREA VS PROJECTILE MASS



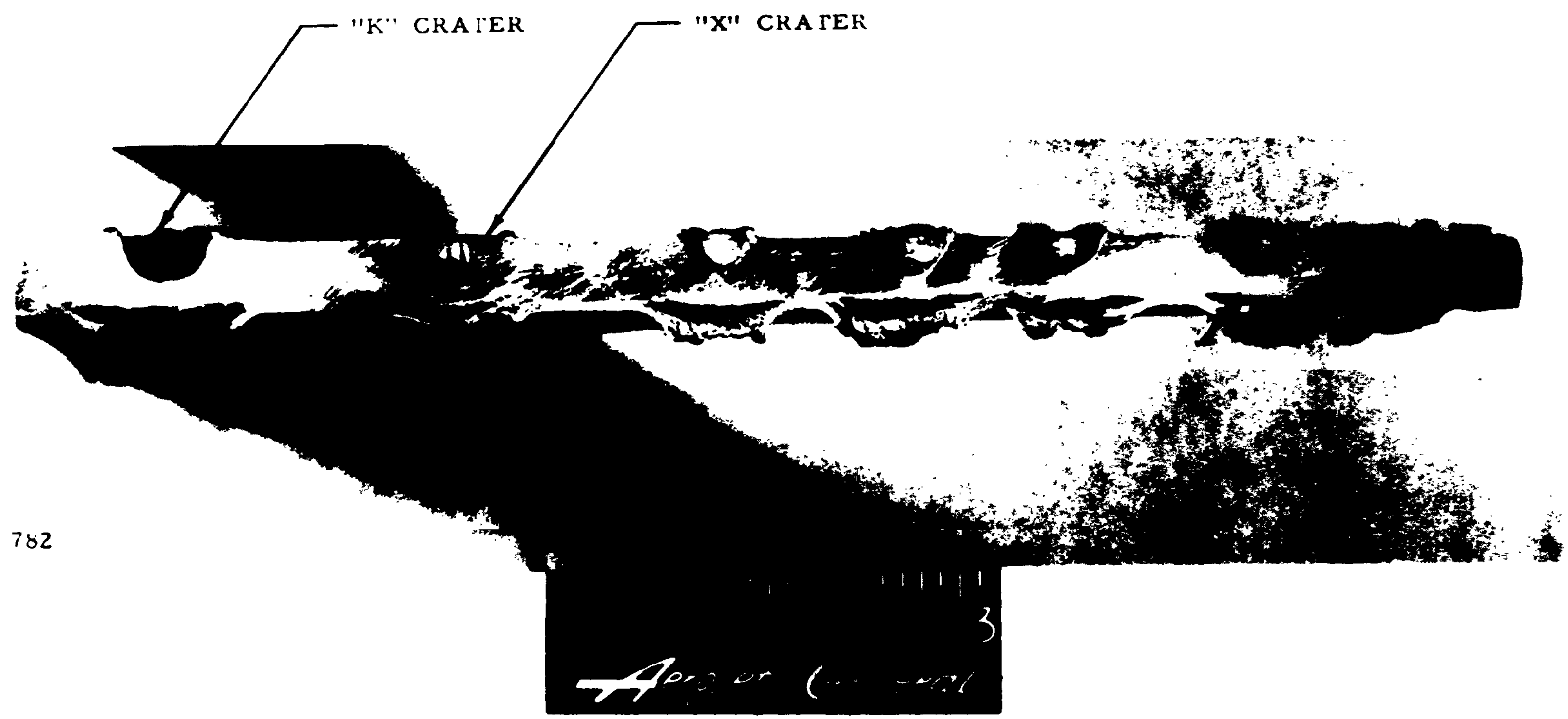
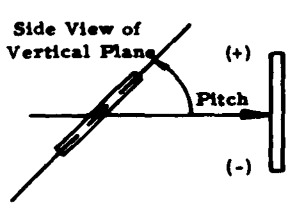


FIGURE 114. SECTIONED VIEW OF TARGET PLATE FROM TEST M-782, SOFT COPPER, 0.500-INCH THICK, 90° OBLIQUITY.

Table 1. Experimental Results, Aluminum Projectiles Fired at 90° Obliquity(6) Into 0.375-inch Thick 2024-T4 Aluminum Target Plates

			Projectile				Orientation			Projected	Target Damage (Crater/Hole Dimensions)				
Test No.	Fig. No.	Designation	Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Pitch (2)	Yaw (3)	Angle of Incidence (4)	Area (in.^{2}) (5)	Depth (in.)	Diameter (in.)	Area (in.^{2})	Vol. (cm^3)	Pressure mm/Hg
M-262	2	B	0.46	0.09/0.12	2.9	33,900	0°	8°R	82°	0.033	Thru	1.01	0.80	---	2.5
	2	C	0.28	0.09/0.10	1.4	33,400	-26°	40°R	46°	0.028		0.70	0.39	---	
M-269	2	A	0.43	0.10/0.14	3.6	32,300	-13°	35°L	54°	0.049		0.85	0.57	---	
	2	C	0.28	0.08/0.12	1.5	31,600	0°	49°L	41°	0.029		0.56	0.25	---	
M-259	2	B	0.82	0.10	4.3	32,400	5°	17°R	72°	0.034		1.03	0.83	---	
M-539	2	B	0.49	0.10/0.13	3.4	31,300	-19°	11°L	68°	0.030		0.77	0.47	---	
M-542	3	A	0.80	0.15/0.13	8.2	32,000	13°	32°L	56°	0.074		1.29	1.31	---	
M-543	3	A	0.85	0.16/0.15	11.0	32,100	40°	79°L	11°	0.135		1.47	1.70	---	
M-544	3	C	0.30	0.15/0.17	4.0	31,500	-60°	54°L	24°	0.060		1.01	0.80	---	
M-547	3	A	0.98	0.15/0.14	10.5	32,000	-13°	9°L	74°	0.136		1.14	1.03	---	
	3	B	0.51	0.11/0.12	3.6	31,700	0°	15°L	75°	0.023		0.88	0.61	---	
M-549	4	A	0.78	0.16/0.16	11.2	32,800	38°	63°L	25°	0.123		1.43	1.61	---	
M-551	5	A	0.84	0.16/0.14	9.9	32,000	-18°	46°L	43°	0.097		1.36	1.45	---	
M-553	5	D	0.28	0.11/0.10	1.6	31,000	-57°	74°R	15°	0.027		0.73	0.42	---	
M-554	5	A	0.78	0.12/0.16	8.5	32,000	-36°	42°L	41°	0.098		1.28	1.29	---	
M-555	6	A	0.81	0.14/0.13	7.7	31,800	0°	4°R	86°	0.021		0.96	0.72	---	
	6	B	0.24	0.11	1.6	31,700	0°	0°	90°	0.010		0.82	0.53	---	
	6	C	0.35	0.11	2.4	31,200	-22°	47°L	41°	0.032		0.94	0.69	---	
M-556	5	A	0.87	0.13/0.18	11.5	31,800	60°	52°L	25°	0.128		1.47	1.69	---	
	5	B	0.35	0.09	1.6	31,100	-76°	76°L	10°	0.030		0.88	0.61	---	
M-563	7	A	0.87	0.14/0.12	7.6	31,800	72°	52°R	17°	0.107		1.32	1.36	---	
M-565	7	A	1.16	0.09/0.14	8.1	32,000	14°	5°L	75°	0.029		1.29	1.32	---	
M-567	7	A	0.85	0.15/0.15	9.9	31,900	88°	88°R	1°	0.124		1.40	1.53	---	
	7	B	0.35	0.12/0.13	2.9	31,200	56°	81°R	9°	0.045	Thru	0.64	0.32	---	2.5

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes.
(3) Yaw is measured from top view radiographs of horizontal planes.
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Area projected onto plane normal to velocity.
(6) Obliquity is angle between velocity and target surface.



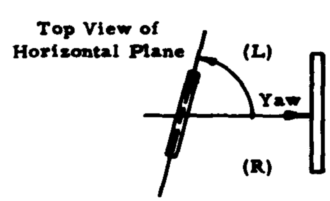


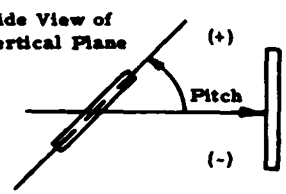
Table 2. Experimental Results, Aluminum Projectiles Fired at 90° Obliquity(6) Into 0.500-inch Thick 2024-T4 Aluminum Target Plates

		Projectile										Target Damage (Crater/Hole Dimensions)				
							Orientation									
Test No.	Fig. No.	Desig-nation	Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Pitch (2)	Yaw (3)	Angle of Incidence (4)	Projected Area ($in.^2$) (5)	Depth (in.)	Diameter (in.)	Area ($in.^2$)	Vol. (cm^3)	Pressure mm/Hg
M-231	8	B	0.56	0.11/0.12	3.8	32,400	44°	0°	46°	0.062	Thru	1.14	1.02	----	2.5
	8	C	0.32	0.09/0.11	1.8	31,300	36°	24°R	50°	0.028	Thru	0.91	0.65	----	2.5
M-232	8	D	0.18	0.12/0.14	1.6	30,800	0°	0°	90°	0.026	0.28	0.61	0.29	0.40	2.5
M-234	8	E	0.43	0.12	3.4	31,000	-88°	0°	2°	0.054	Thru	0.92	0.67	----	2.0
M-237	8	B	0.30	0.10/0.16	2.6	31,700	8°	70°L	20°	0.040	Thru	1.05	0.86	----	2.0
	8	C	0.19	0.07/0.12	0.8	31,500	0°	50°L	40°	0.013	Thru	0.79	0.49	----	2.0
	8	D	0.34	0.08/0.11	1.6	31,200	0°	51°L	39°	0.029	Thru	0.85	0.56	----	2.0
M-243	9	A	0.54	0.15/0.10	4.3	32,200	-58°	55°L	25°	0.061	Thru	0.88	0.61	----	3.0
M-248	9	B	0.45	0.10/0.15	3.4	32,500	43°	53°R	32°	0.053	Thru	1.06	0.88	----	3.0
M-277	9	A	0.66	0.10/0.12	4.3	32,600	-62°	22°R	27°	0.072	Thru	1.12	0.99	----	2.0
	9	B	0.22	0.11/0.13	1.7	32,500	0°	78°L	12°	0.033	Thru	0.78	0.47	----	↑
M-315	11	B	0.18	0.11	1.1	33,000	0°	0°	90°	0.019	0.35	0.76	0.45	0.90	│
	11	C	0.26	0.09	1.1	32,900	-13°	0°	77°	0.014	0.38	0.70	0.38	0.80	│
	11	D	0.29	0.12	2.3	32,400	37°	5°L	53°	0.026	Thru	0.79	0.49	----	│
M-316	10	A	0.48	0.13/0.14	4.7	32,800	0°	2°R	88°	0.024	Thru	1.05	0.86	----	│
	10	B	0.21	0.14/0.15	2.4	32,300	0°	0°	90°	0.031	Thru	1.02	0.81	----	│
	10	C	0.05	0.17	0.8	32,100	0°	0°	90°	0.009	0.34	0.70	0.38	0.80	│
M-317	9	C	0.34	0.18/0.09	1.3	31,600	88°	81°L	2°	0.029	0.45	0.84	0.55	1.70	↓
M-477	12	A	1.03	0.15/0.13	10.6	32,500	- 2°	15°R	75°	0.034	Thru	1.02	0.81	----	2.0
M-478	12	A	0.91	0.13/0.15	9.6	33,600	0°	13°R	77°	0.044	Thru	1.47	1.17	----	2.5
	12	B	0.16	0.11	1.0	33,100	-40°	2°R	50°	0.018	0.44	0.81	0.51	----	2.5

(Continued on next page)

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes.
(3) Yaw is measured from top view radiographs of horizontal planes.
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Area projected onto plane normal to velocity.
(6) Obliquity is angle between velocity and target surface.

Side View of Vertical Plane



Top View of Horizontal Plane

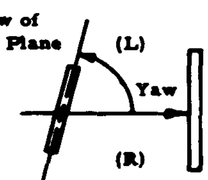


Table 2 (Cont'd). Experimental Results, Aluminum Projectiles Fired at 90° Obliquity[6] Into 0.500-inch Thick 2024-T4 Aluminum Target Plates

Test No.	Fig. No.	Projectile: Designation	Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Pitch (2)	Yaw (3)	Angle of Incidence (4)	Projected Area (in.^{2}) (5)	Target Damage (Crater/Hole Dimensions): Depth (in.)	Diameter (in.)	Area (in.^{2})	Vol. (cm^3)	Pressure mm/Hg
M-484	13	C	0.21	0.12/0.09	1.2	32,100	-28°	36°L	48°	0.022	----	0.80	0.50	----	2.5
M-485	13	A	0.92	0.15/0.13	9.4	32,700	3°	4°L	85°	0.029	Thru	1.21	1.15	----	2.0
M-486	13	A	0.61	0.18	10.3	32,300	-23°	55°L	34°	0.091	Thru	1.29	1.31	----	2.0'
M-488	13	A	1.14	0.15/0.12	11.2	34,000	-61°	80°R	9°	0.150	Thru	1.42	1.62	----	2.0
M-499	14	D	0.50	0.10/0.17	4.7	32,500	70°	13°L	20°	0.063	Thru	1.17	1.08	----	2.5
	14	E	0.24	0.16/0.11	2.4	32,100	-60°	35°R	28°	0.036	Thru	0.91	0.65	----	2.5
M-533	14	E	0.23	0.11/0.13	1.9	32,400	70°	55°L	18°	0.029	0.40	0.76	0.45	----	2.5
M-534	14	A	0.91	0.16/0.15	11.7	32,100	0°	90°	0°	0.140	Thru	1.30	1.33	----	2.5
M-535	15	A	0.91	0.12/0.14	8.5	33,100	86°	15°L	4°	0.118	Thru	1.39	1.51	----	2.5
	15	B	0.17	0.11/0.13	1.3	32,900	90°	0°	0°	0.020	Thru	0.87	0.60	----	2.5
M-537	16	A	1.00	0.15/0.14	11.3	32,900	58°	37°L	29°	0.134	Thru	1.61	2.03	----	2.5
M-538	14	A	0.69	0.13	6.0	32,000	83°	55°R	7°	0.088	Thru	1.02	0.82	----	2.5
M-66	11	C	----	0.15	1.2	27,800	NA	NA	90°	0.018	Thru	0.81	0.51	----	1.5
M-273	17	A	0.73	0.13/0.15	7.6	32,700	6°	8°R	80°	0.046	Thru	1.04	0.86	----	2.0
		B	0.74	0.08/0.13	1.3	32,400	81°	27°L	9°	0.024	Thru	0.75	0.44	----	2.0
		C	0.56	0.08/0.12	3.0	32,100	14°	0°	76°	0.028	Thru	0.98	0.75	----	2.0

Table 3. Experimental Results, Aluminum Projectiles Fired at 90° Obliquity(5) Into 1.00-inch Thick 2024-T4 Aluminum Target Plates

			Projectile				Orientation			Target Damage (Crater/Hole Dimensions)				
Test No.	Fig. No.	Desig-nation	Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Pitch (2)	Yaw (3)	Angle of Incidence (4)	Depth (in.)	Diameter (in.)	Area (in.^{2})	Vol. (cm^3)	Pressure mm/Hg
M-304	18	A	0.59	0.14/0.15	6.9	22,000	- 3°	8°R	80°	Thru	1.38	1.49	---	2.0
M-305	20	A	0.69	0.17	10.2	31,500	-13°	28°R	60°	Thru	1.18	1.40	---	
M-307	19	A	0.38	0.10	2.1	31,400	52°	13°L	38°	0.32	0.84	0.56	1.4	
	19	C	0.29	0.12/0.13	2.4	30,000	-62°	0°	28°	0.30	0.70	0.38	1.0	
M-311	20	D	0.31	0.11	2.1	31,500	-58°	36°L	30°	0.34	0.82	0.53	1.6	
	20	E	0.35	0.13	3.1	30,900	19°	36°R	51°	0.32	0.70	0.38	0.9	
M-312	20	B	0.37	0.10	1.8	30,300	-72°	68°L	14°	0.35	0.80	0.50	1.4	
	20	C	0.21	0.10	1.1	30,100	0°	0°	90°	0.28	0.74	0.43	0.7	
M-314	20	B	0.38	0.12	3.0	30,300	-65°	0°	25°	0.33	0.78	0.48	1.5	
	20	D	0.43	0.09/0.13	2.7	30,000	- 8°	20°L	69°	0.47	0.71	0.40	1.9	
M-322	19	D	0.29	0.12/0.18	2.9	32,100	42°	0°	48°	0.39	0.78	0.48	1.2	
M-698	22	B	0.21	0.14/0.15	2.3	31,400	62°	62°R	21°	0.36	0.87	0.60	2.9	
	22	C	0.23	0.15/0.08	1.5	31,000	-14°	1°R	76°	0.36	0.81	0.51	1.6	
	22	D	0.31	0.15/0.14	3.4	30,500	82°	55°L	8°	0.33	0.93	0.68	1.5	
	22	E	0.29	0.10/0.14	2.1	30,000	13°	16°R	70°	0.46	0.79	0.49	1.8	
M-699	21	A	0.85	0.15/0.13	8.5	32,200	- 5°	17°L	72°	Thru	1.35	1.38	---	
M-701	23	X	0.42	0.09/0.11	2.3	31,200	-43°	37°L	40°	0.39	0.74	0.43	1.8	
	23	Y	0.36	0.10/0.11	2.1	30,000	89°	38°L	52°	0.32	0.79	0.49	1.4	
M-702	23	B	0.34	0.10/0.15	2.8	32,000	48°	45°L	34°	0.37	0.89	0.62	2.2	
M-704	23	D	0.18	0.15/0.10	1.	26,000	0	89°L	1°	0.31	0.75	0.44	1.1	
M-705	23	A	0.97	0.13/0.16	10.7	32,500	53°	34°L	34°	Thru	1.46	1.67	---	
M-706	22	A	0.56	0.13/0.14	5.2	32,500	41°	9°L	49°	0.60	1.27	1.28	6.4	
	22	B	0.41	0.17/0.18	6.6	31,800	-88°	83°R	2°	0.49	1.06	0.89	3.9	2.0

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes.
(3) Yaw is measured from top view radiographs of horizontal planes.
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Obliquity is angle between velocity and target surface.

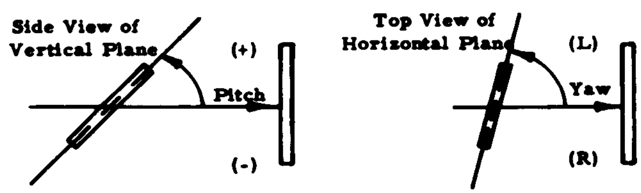
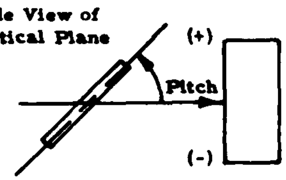


Table 4. Experimental Results, Aluminum Projectiles Fired at 50° Obliquity(5) Into 0.375-inch Thick 2024-T4 Aluminum Target Plates

Test No.	Fig. No.	Desig-nation	Projectile: Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Pitch (2)	Yaw (3)	Angle of Incidence (4)	Projected Area ($in.^2$) (6)	Target Damage (Crater/Hole Dimensions): Depth (in.)	Diameter (in.)	Area ($in.^2$)	Vol. (cm^3)	Pressure (mm/Hg)
M-570	24	A	0.53	. 0.16	7.2	31,000	79°	59°R	19°	0.082	Thru	1.29	1.30	NA	2.5
	24	C	0.20	0.10/0.14	1.5	30,900	33°	80°R	50°	0.022		0.75	0.44		
M-572	24	A	0.89	0.16/0.15	11.0	30,900	63°	26°L	12°	0.116		1.20	1.12		
M-573	24	A	0.81	0.15/0.12	7.9	33,200	89°	66°L	1°	0.107		1.17	1.07		
M-574	24	X	0.35	0.10/0.09	1.6	31,400	69°	56°L	3°	0.032		0.74	0.43		
M-575	25	X	0.28	0.13/0.12	2.3	30,600	-26°	44°L	6°	0.033		0.84	0.56		
	25	Y	0.21	0.11/0.09	1.2	30,500	68°	0°	17°	0.020		0.65	0.33		
M-576	25	X	0.21	0.06/0.11	0.8	30,900	77°	58°L	3°	0.019		0.64	0.32		
	25	Z	0.26	0.10/0.14	1.9	30,300	-32°	43°R	65°	0.029		0.77	0.47		
M-577	25	C	0.30	0.11/0.12	2.2	30,700	38°	16°L	27°	0.029		0.89	0.62		
M-685	26	A	0.67	0.15	8.1	32,400	82°	87°L	3°	0.100		1.27	1.20		
M-687	25	C	0.20	0.15/0.10	1.7	30,800	32°	17°R	52°	0.024		0.86	0.58		
M-691	26	A	0.91	0.14/0.15	10.2	31,500	50°	20°R	39°	0.121		1.31	1.32		
M-692	26	C	----	0.10	0.4	30,500	NA	NA	NA	0.008		0.73	0.42		
M-694	26	A	0.83	0.15/0.17	11.0	31,500	38°	18°R	50°	0.096		1.24	1.15		
M-696	27	A	0.66	0.16/0.14	8.1	31,400	-27°	32°L	16°	0.076		1.29	1.30		
	27	B	0.33	0.13/0.12	2.8	30,800	53°	56°L	5°	0.040		0.83	0.54		
M-712	28	D	0.19	0.15/0.09	1.3	31,600	51°	36°R	45°	0.023		0.70	0.38		
M-713	28	D	0.24	0.13/0.09	1.5	31,500	-23°	45°R	73°	0.024		1.03	0.84		
M-714	27	A	0.86	0.13/0.15	9.6	31,700	-23°	63°R	65°	0.112		1.26	1.19		
	27	B	0.28	0.12/0.16	2.8	30,900	21°	23°R	64°	0.031	Thru	0.91	0.65	NA	2.5

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes.
(3) Yaw is measured from top view radiographs of horizontal planes.
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Obliquity is angle between velocity and target surface.
(6) Area projected onto plane normal to velocity.

Side View of Vertical Plane



Top View of Horizontal Plane

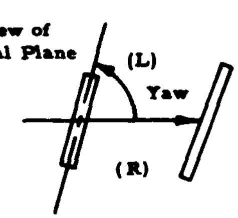
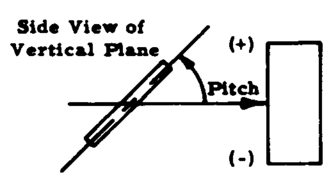


Table 5. Experimental Results, Aluminum Projectiles Fired at 50° Obliquity(5) Into 0.500-inch Thick 2024-T4 Aluminum Target Plates

			Projectile				Orientation			Target Damage (Crater/Hole Dimensions)				
Test No.	Fig. No.	Desig-nation	Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Pitch (2)	Yaw (3)	Angle of Incidence (4)	Depth (in.)	Diameter (in.)	Area (in.^{2})	Vol. (cm^3)	Pressure (mm/Hg)
M-253	29	A	0.59	0.12/0.18	6.8	32,800	-37°	63°R	61°	Thru	1.22	1.15	----	3.0
	29	B	0.49	0.13	4.6	32,800	-65°	0°	19°	Thru	0.94	0.69	----	3.0
M-254	30	A	0.75	0.15	9.0	33,100	- 3°	49°R	81°	Thru	1.19	1.09	----	3.0
	30	B	0.33	0.12/0.14	3.0	32,900	0°	45°L	5°	Thru	0.87	0.59	----	3.0
M-260	30	D	0.25	0.06/0.08	0.8	31,900	0°	30°L	20°	0.24	0.48	0.18	0.40	3.0
M-610	29	A	0.58	0.14/0.15	6.9	31,300	-21°	24°R	65°	Thru	1.20	1.11	----	2.0
	29	B	0.23	0.10/0.14	1.8	31,100	29°	1°L	41°	Thru	0.93	0.68	----	2.0
M-611	30	B	0.30	0.10	1.6	31,800	-47°	36°L	10°	0.33	0.87	0.59	1.78	2.0
	30	E	0.18	0. 0.10	0.9	31,000	64°	67°L	13°	0.25	0.66	0.34	1.06	2.0
M-613	31	F	0.25	0.11/0.05	0.7	30,800	17°	22°R	66°	0.22	0.66	0.34	0.34	2.0
M-618	30	C	0.23	0.12/0.11	1.7	31,100	47°	43°L	5°	0.36	0.74	0.43	----	2.0
	30	D	0.19	0.13/0.10	1.3	30,900	18°	8°R	54°	Thru	0.76	0.45	----	2.0
M-655	31	A	0.80	0.14/0.16	9.7	30,800	24°	3°R	66°	Thru	1.34	1.33	----	2.0

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes.
(3) Yaw is measured from top view radiographs of horizontal planes.
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Obliquity is angle between velocity and target surface.



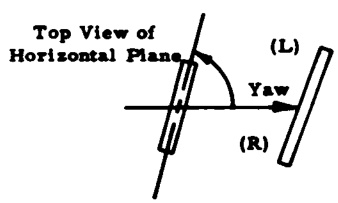
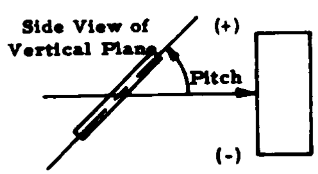


Table 6. Experimental Results, Aluminum Projectiles Fired at 50° Obliquity(5) Into 1.00-inch Thick 2024-T4 Aluminum Target Plates

Test No.	Fig. No.	Designation	Projectile: Length (in.)	Projectile: Diameter (in.) (1)	Projectile: Mass (grains)	Projectile: Velocity (ft/sec)	Orientation: Pitch (2)	Orientation: Yaw (3)	Orientation: Angle of Incidence (4)	Target Damage (Crater/Hole Dimensions): Depth (in.)	Target Damage: Diameter (in.)	Target Damage: Area (in.^{2})	Target Damage: Vol. (cm^3)	Pressure (mm/Hg)
M-707	32	A	0.77	0.16/0.11	7.4	32,000	-40°	42°L	7°	0.61	1.54	1.86	10.58	2.0
	32	B	----	0.14/0.13	1.2	31,500	NA	NA	NA	0.24	0.76	0.45	0.24	
	32	C	0.25	0.08/0.09	1.0	31,200	-68°	64°	9°	0.27	0.77	0.47	0.76	
M-709	33	B	0.32	0.11/0.15	2.8	31,300	11°	55°L	5°	0.32	0.96	0.72	2.28	
	33	C	0.25	0.11	1.6	30,800	-71°	69°L	13°	0.27	0.68	0.36	1.00	
	33	D	0.24	0.10/0.08	1.1	30,600	-33°	50°R	65°	0.22	0.59	0.27	0.72	
M-711	34	D	0.25	0.13/0.12	2.2	30,400	0°	90°	40°	0.30	0.81	0.52	1.24	
M-716	34	B	0.24	0.09/0.14	1.8	31,100	22°	15°L	64°	0.34	0.89	0.63	1.36	
	34	D	0.17	0.08/0.07	0.5	30,800	-76°	44°L	14°	0.21	0.46	0.17	0.48	2.0

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes.
(3) Yaw is measured from top view radiographs of horizontal planes.
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Obliquity is angle between velocity and target surface.



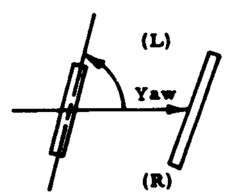


Table 7. Experimental Results, Aluminum Projectiles Fired at 20° Obliquity(5) Into 0.375-inch Thick 2024-T4 Aluminum Target Plates

		Projectile					Orientation				Target Damage (Crater/Hole Dimensions)				
Test No.	Fig. No.	Designation	Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Pitch (2)	Yaw (3)	Angle of Incidence (4)	Projected Area (in.^{2}) (6)	Depth (in.)	Diameter (in.)	Area (in.^{2})	Vol. (cm^3)	Pressure mm/Hg
M-795	35	A	0.61	0.12/0.13	5.3	31,600	17°	52°R	69°	0.066	Thru	0.98	0.75	NA	2.5
M-796	35	A	0.58	0.12/0.14	5.2	30,100	-10°	11°R	30°	0.029	Thru	1.10	0.90		
M-797	35	B	0.18	0.10/0.10	1.0	31,300	-26°	12°R	29°	0.016	NA	0.62	0.30		
M-803	35	A	0.60	0.15/0.14	7.1	30,900	5°	40°L	20°	0.068	Thru	0.66	0.34		
	35	B	0.22	0.07/0.12	1.0	30,500	40°	9°L	8°	0.016	NA	0.32	0.08		
M-806	36	A	0.46	0.14	5.2	30,300	87°	79°L	13°	0.066	Thru	0.92	0.66		
M-809	37	C	0.32	0.10/0.08	1.5	29,900	46°	50°L	25°	0.028	NA	0.80	0.50		
M-810	36	A	0.47	0.13/0.16	5.5	31,400	- 4°	20°L	0°	0.037	NA	1.01	0.81		
M-811	37	A	0.83	0.13/0.14	7.8	32,200	-81°	88°L	45°	0.110	NA	0.95	0.71		
M-812	38	A	0.68	0.13	6.6	31,000	-68°	83°R	69°	0.091	Thru	0.84	0.56		
	38	C	0.19	0.14/0.10	1.3	30,400	NA	NA	NA	0.021	NA	0.42	0.14		
M-813	38	C	0.28	0.07	0.7	30,500	0°	85°L	78°	0.019	NA	0.50	0.20	NA	2.5

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes.
(3) Yaw is measured from top view radiographs of horizontal planes.
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Obliquity is angle between velocity and target surface.
(6) Area projected onto plane normal to velocity.

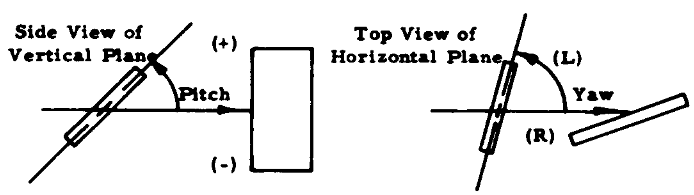


Table 8. Experimental Results, Aluminum Projectiles Fired at 20° Obliquity(5) Into 0.500-inch Thick 2024-T4 Aluminum Target Plates

Test No.	Fig. No.	Desig-nation	Projectile: Length (in.)	Projectile: Diameter (in.) (1)	Projectile: Mass (grains)	Projectile: Velocity (ft/sec)	Orientation: Pitch (2)	Orientation: Yaw (3)	Orientation: Angle of Incidence (4)	Target Damage (Crater/Hole Dimensions): Depth (in.)	Target Damage: Diameter (in.)	Target Damage: Area (in.^{2})	Target Damage: Vol. (cm^3)	Pressure (mm/Hg)
M-264	39	A	0.65	0.13/0.14	9.0	31,100	-48°	0°	13°	Thru	0.98	0.75	----	2.5
M-267	39	B	0.29	0.07/0.13	1.6	31,400	39°	33°R	41°	0.08	0.47	0.17	0.10	2.0
M-623	40	A	0.58	0.16/0.14	7.3	31,700	-47°	52°R	52°	Thru	1.01	0.81	----	2.5
M-624	40	B	0.16	0.09/0.12	1.1	31,700	-17°	6°L	13°	0.13	0.48	0.18	0.14	2.5
	40	C	0.20	0.14/0.09	1.4	31,700	30°	4°R	60°	0.13	0.48	0.18	0.10	2.5
	40	D	0.19	0.13/0.11	1.4	30,800	-14°	9°R	74°	0.12	0.48	0.18	0.09	2.5
M-626	41	A	0.72	0.15/0.13	7.7	31,700	3°	31°R	59°	Thru	0.95	0.71	----	2.5
	41	B	0.24	0.11	1.5	31,400	-50°	0°	40°	0.18	0.52	0.21	0.22	2.5

Notes: (1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.

(2) Pitch is measured from side view radiographs of vertical planes.

(3) Yaw is measured from top view radiographs of horizontal planes.

(4) Angle of Incidence: Angle between major axis of projectile and target.

(5) Obliquity is angle between velocity and target surface.

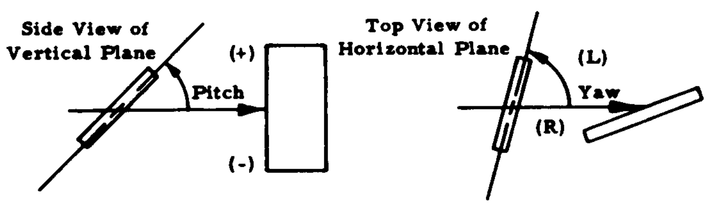


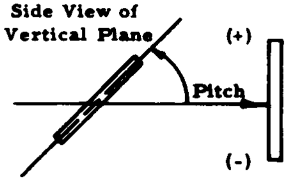
Table 9. Experimental Results, Aluminum Projectiles Fired at 90° Obliquity(5) Into 4.0-inch Thick 2024-T4 Aluminum Target Plates

Test No.	Fig. No.	Designation	Projectile Length (in.)	Projectile Diameter (in.) (1)	Projectile Mass (grains)	Projectile Velocity (ft/sec)	Orientation Pitch (2)	Orientation Yaw (3)	Orientation Angle of Incidence (4)	Depth/Dia. (P/d) (6)	Target Damage (Crater/Hole Dimensions) Depth (in.)	Target Damage Diameter (in.)	Target Damage Area ($in.^2$)	Target Damage Vol. (cm^3)	Pressure mm/Hg
M-81	59	A	0.80	0.14	8.4	31,600	32°	35°L	47°	1.99	0.57	1.35	1.43	9.10	2.0
M-83	59	A	0.46	0.14	4.8	31,200	2°	25°L	65°	2.73	0.65	1.22	1.16	6.28	1.5
	59	B	0.32	0.08	1.1	30,500	57°	70°R	18°	1.93	0.28	0.73	0.42	0.90	1.5
M-334	60	C	0.23	0.10/0.08	1.0	29,000	0°	80°R	10°	1.77	0.28	0.68	0.36	0.91	2.0
	60	D	0.41	0.08/0.19	3.2	28,700	2°	72°L	18°	1.68	0.35	1.00	0.78	2.42	
M-335	60	D	0.34	0.12	2.6	30,900	5°	72°L	18°	1.81	0.35	0.80	0.50	2.16	
	60	E	0.29	0.08/0.13	1.7	30,500	18°	69°R	21°	1.85	0.31	0.70	0.38	1.30	
M-336	60	B	0.38	0.15/0.12	3.1	33,500	- 7°	25°R	65°	2.04	0.42	0.83	0.54	2.79	
	60	E	0.34	0.12/0.14	3.0	32,500	22°	35°R	51°	2.06	0.42	0.96	0.73	2.10	
M-337	60	A	1.03	0.12/0.13	8.6	32,500	11°	36°R	53°	2.35	0.68	1.38	1.50	10.60	
	60	B	0.22	0.09/0.10	1.1	31,500	-68°	0°	22°	2.07	0.30	0.62	0.30	1.06	
	60	C	0.27	0.06/0.08	1.2	31,400	41°	40°R	40°	1.47	0.22	0.53	0.22	0.59	
M-338	61	D	0.39	0.11/0.09	2.1	31,300	-82°	68°L	8°	1.83	0.33	0.81	0.51	1.96	
M-340	61	C	0.25	0.13/0.11	1.9	32,300	64°	79°R	10°	1.66	0.29	0.71	0.40	1.18	
	61	D	----	0.17	1.8	31,900	NA	NA	90°	2.14	0.37	0.86	0.58	1.91	
	61	E	0.25	0.10/0.12	1.5	31,400	-12°	21°L	66°	2.16	0.35	0.71	0.39	2.46	
M-342	61	A	0.58	0.14/0.15	6.6	31,600	-58°	21°R	31°	1.97	0.52	1.38	1.50	7.93	
	61	B	0.49	0.11/0.10	2.9	31,000	89	59°L	1°	1.99	0.40	1.03	0.83	3.32	
	61	C	0.32	0.12/0.11	2.2	30,600	62°	88°R	2°	1.80	0.33	0.74	0.43	1.56	
M-343	61	A	0.69	0.10/0.17	6.1	32,800	-22°	37°R	49°	2.21	0.57	1.49	1.75	9.90	

(Continued on next page)

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes.
(3) Yaw is measured from top view radiographs of horizontal planes.
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Obliquity is angle between velocity and target surface.
(6) P is the crater depth; d is the equivalent diameter for a spherical projectile having the listed mass.

Side View of Vertical Plane



Top View of Horizontal Plane

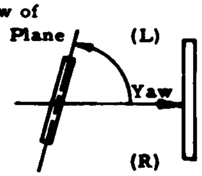


Table 9 (Cont'd). **Experimental Results, Aluminum Projectiles Fired at 90° Obliquity[5] Into 4.0-inch Thick 2024-T4 Aluminum Target Plates**

		Projectile					Orientation				Target Damage (Crater/Hole Dimensions)				
Test No.	Fig. No.	Designation	Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Pitch (2)	Yaw (3)	Angle of Incidence (4)	Depth/Dia. (P/d) (6)	Depth (in.)	Diameter (in.)	Area (in.^{2})	Vol (cm^3)	Pressure mm/Hg
M-344	62	C	0.78	0.11/0.13	5.8	33,100	75°	44°L	15°	1.74	0.44	1.28	1.29	5.77	2.0
	62	D	0.26	0.08/0.13	1.5	32,900	0°	51°L	39°	1.92	0.31	0.76	0.45	1.28	
M-345	66	B	0.44	0.12	3.4	33,600	- 4°	35°L	55°	2.22	0.47	0.86	0.58	3.10	
	66	C	0.13	0.08/0.12	0.7	33,000	NA	NA	90°	2.56	0.32	0.57	0.26	0.68	
	66	D	0.28	0.08/0.11	1.4	32,600	-53°	30°L	35°	1.95	0.31	0.64	0.32	1.39	
M-346	62	B	0.31	0.08/0.09	1.3	33,100	0°	57°L	33°	2.16	0.34	0.76	0.45	1.39	
M-348	62	B	0.48	0.14/0.11	3.7	33,500	-19°	53°R	36°	1.56	0.34	0.90	0.64	2.84	
	62	C	0.40	0.10/0.12	2.5	32,000	49°	11°L	41°	1.41	0.27	0.73	0.42	1.44	
M-349	63	C	0.40	0.18/0.10	3.6	28,600	0°	89°R	1°	1.53	0.33	0.86	0.58	1.59	
M-351	64	X	0.19	0.09/0.11	1.0	31,700	0°	21°L	69°	2.13	0.30	0.70	0.38	1.01	
	64	Y	0.26	0.15/0.11	2.3	31,600	20°	4°R	70°	2.20	0.41	0.71	0.39	1.87	
M-352	63	A	0.27	0.15	3.3	32,300	72°	69°L	14°	1.62	0.34	0.92	0.67	1.72	
	63	B	0.20	0.14/0.12	1.8	31,800	-54°	55°L	27°	1.62	0.28	0.66	0.34	0.74	
	63	C	0.28	0.15/0.13	3.0	31,800	-19°	72°L	18°	1.52	0.31	0.81	0.51	1.34	
	63	D	0.20	0.15/0.07	1.1	31,600	- 4°	47°L	43°	1.79	0.26	0.61	0.29	0.76	
M-353	64	C	0.21	0.10/0.11	1.2	32,100	- 8°	5°L	81°	2.67	0.40	0.77	0.46	1.61	
M-354	65	C	0.05	0.22/0.25	1.6	27,400	NA	NA	90°	1.76	0.29	0.54	0.23	0.77	
M-355	65	D	0.23	0.13	2.2	32,000	25°	22°R	58°	1.86	0.34	0.68	0.36	1.17	
	65	E	0.26	0.11/0.14	2.1	31,700	64°	36°L	25°	1.67	0.30	0.70	0.38	1.18	
M-356	65	A	0.68	0.15	7.8	28,000	-27°	45°L	42°	2.29	0.64	1.68	2.21	10.90	
	65	B	0.42	0.10/0.12	2.9	27,100	12°	31°L	57°	1.85	0.38	0.92	0.67	2.20	
M-362	65	D	0.21	0.08/0.11	1.1	30,300	17°	73°R	17°	1.50	0.22	0.63	0.31	0.69	
M-363	66	A	0.77	0.15	9.0	34,000	-36°	15°R	52°	2.53	0.74	1.38	1.49	10.96	
	66	B	0.06	0.22	1.5	33,600	NA	NA	90°	1.67	0.27	0.47	0.17	0.80	

Table 9 (Cont'd). Experimental Results, Aluminum Projectiles Fired at 90° Obliquity[5] Into 4.0-inch Thick 2024-T4 Aluminum Target Plates

Test No.	Fig. No.	Projectile Designation	Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Orientation Pitch (2)	Yaw (3)	Angle of Incidence (4)	Depth/Dia. (P/d) (6)	Target Damage (Crater/Hole Dimensions) Depth (in.)	Diameter (in.)	Area (in.^{2})	Vol. (cm^3)	Pressure mm/Hg
M-364	66	C	0.26	0.08/0.11	1.3	31,900	-25°	30°R	53°	2.08	0.32	0.80	0.50	1.45	2.0
	66	D	0.36	0.08/0.11	1.8	30,700	-22°	45°L	43°	1.74	0.30	0.81	0.51	1.51	
	66	E	0.30	0.21	2.3	30,600	0°	46°R	44°	1.72	0.32	0.71	0.40	1.10	
M-365	66	C	0.23	0.10/0.12	1.5	30,700	-51°	62°L	24°	1.54	0.25	0.71	0.40	0.73	
M-366	62	B	0.22	0.15/0.10	1.7	31,000	41°	27°R	45°	1.72	0.29	0.59	0.27	0.82	
	62	D	0.64	0.15/0.13	6.5	30,500	71°	20°L	19°	1.90	0.50	1.31	1.35	4.94	
M-369	67	A	0.58	0.12/0.19	7.1	27,000	-15°	39°L	50°	2.58	0.70	1.38	1.50	7.76	
	67	C	0.25	0.07/0.08	0.7	26,800	80°	65°L	9°	1.36	0.17	0.49	0.19	0.79	2.0
M-374	67	B	0.42	0.08/0.09	1.8	30,700	0°	88°L	2°	1.85	0.32	0.78	0.48	1.39	2.5
M-376	69	X	0.30	0.12	0.8	30,800	62°	18°L	28°	1.68	0.22	0.52	0.21	0.30	2.0
M-377	67	A	0.50	0.14/0.17	6.5	32,100	-62°	57°R	23°	1.87	0.49	1.13	0.98	5.73	
	67	D	0.33	0.09/0.15	2.3	32,000	-33°	17°R	54°	2.10	0.39	0.86	0.46	1.82	
M-378	68	D	0.20	0.12/0.11	1.5	30,500	-52°	15°L	37°	1.98	0.32	0.70	0.38	1.22	
	68	E	0.20	0.12/0.09	1.1	30,100	-38°	15°L	50°	2.19	0.32	0.64	0.32	0.90	2.0
M-379	68	A	0.67	0.12/0.19	8.8	32,900	-11°	47°R	44°	2.20	0.64	1.38	1.49	9.27	2.5
M-380	68	A	0.74	0.15/0.16	9.2	32,500	-18°	7°R	71°	2.75	0.81	1.55	1.88	15.95	2.0
	68	C	0.18	0.07/0.11	0.7	30,600	33°	27°R	50°	2.48	0.31	0.62	0.30	1.10	
M-381	68	B	0.77	0.09/0.11	3.6	31,700	-85°	88°L	2°	1.95	0.42	1.17	1.07	3.72	
	68	C	0.07	0.18/0.19	1.5	31,000	NA	NA	90°	1.42	0.23	0.62	0.30	0.61	
M-382	69	E	0.31	0.11	2.0	30,800	-28°	13°R	60°	2.08	0.37	0.66	0.34	1.62	
M-383	67	B	0.32	0.12/0.16	3.4	31,400	44°	70°R	19°	1.70	0.36	0.84	0.55	2.10	
	67	C	0.29	0.11/0.14	2.4	31,400	88°	0°	2°	1.59	0.30	0.92	0.67	1.58	
	67	D	0.34	0.15/0.12	3.4	30,400	-42°	52°R	33°	1.46	0.31	0.90	0.63	1.71	
M-384	69	D	0.30	0.08/0.14	1.9	31,700	31°	27°R	52°	2.12	0.37	0.66	0.34	1.24	
	69	E	0.08	0.13/0.14	1.1	30,400	12°	0°	78°	2.14	0.31	0.63	0.31	0.89	
M-385	69	B	0.27	0.12	2.2	32,400	37°	53°L	33°	1.80	0.33	0.73	0.42	1.32	
	69	C	0.34	0.13/0.14	3.4	32,400	-89°	75°L	1°	1.56	0.33	0.73	0.42	1.61	2.0

Table 10. Experimental Results, Aluminum Projectiles Fired at 90° Obliquity[(6)] into 0.100-inch Thick 2024-T4 Aluminum Target Plates

Test No.	Fig. No.	Desig-nation	Projectile: Length (in.)	Projectile: Diameter (in.) (1)	Projectile: Mass (grains)	Projectile: Velocity (ft/sec)	Orientation: Pitch (2)	Orientation: Yaw (3)	Orientation: Angle of Incidence (4)	Projected Area (in.) (5)	Target Damage (Crater/Hole Dimensions): Depth (in.)	Target Damage: Diameter (in.)	Target Damage: Area (in.^{2})	Target Damage: Vol. (cm^3)	Pressure (mm/Hg)
M-324	70	A	0.85	0.15/0.12	8.6	37,500	-16°	10°R	71°	0.043	Thru	0.67	0.35	NA	2.0
M-451	70	A	0.35	0.11/0.17	3.7	37,300	21°	8°R	68°	0.034		0.76	0.46		
M-458	70	A	0.54	0.16/0.14	6.4	37,500	-20°	8°R	69°	0.040		0.65	0.33		
M-522	70	A	0.43	0.16/0.14	5.0	36,100	- 7°	6°R	81°	0.028		0.58	0.26		
	70	B	0.30	0.12/0.13	2.1	36,000	71°	45°L	18°	0.031		0.70	0.39		
M-592	71	A	0.62	0.13/0.12	5.1	36,900	-70°	88°R	2°	0.073		1.00	0.78		
	71	B	0.17	0.14/0.08	1.1	36,300	39°	29°L	46°	0.020		0.55	0.24		
M-787	71	A	0.78	0.15/0.17	10.9	37,300	-43°	78°R	12°	0.126		1.12	1.00		
M-843	73	B	0.57	0.15/0.11	5.0	37,400	-41°	53°R	32°	0.068		0.84	0.55		
M-849	72	A	0.66	0.16/0.14	8.0	39,500	13°	58°L	32°	0.095		1.06	0.80		
	72	X	0.15	0.06/0.05	0.2	39,000	87°	81°R	3°	0.008		0.45	0.16		
M-851	72	X	0.22	0.06/0.05	0.3	39,000	-21°	20°R	62°	0.007		0.41	0.13		
M-881	73	A	0.57	0.13/0.17	6.9	35,400	-31°	31°R	50°	0.065		0.87	0.59		
M-891	74	A	0.49	0.14/0.16	5.9	36,300	11°	36°R	53°	0.052		0.72	0.41		
M-892	74	A	0.82	0.11/0.13	6.7	36,400	-62°	66°R	19°	0.101		1.01	0.80		
M-893	74	A	0.75	0.14/0.10	5.7	37,100	38°	49°R	36°	0.078		1.00	0.78		
M-901	74	D	0.25	0.11/0.10	1.5	36,500	-80°	66°L	9°	0.027		0.66	0.34		
M-902	75	A	1.14	0.16/0.12	12.2	38,000	52°	44°L	32°	0.147		1.12	0.99		
	75	D	0.31	0.10/0.14	2.3	37,900	15°	53°R	32°	0.028	Thru	0.66	0.34	NA	2.0

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes (Planes V-V in Figures 70 to 75).
(3) Yaw is measured from top view radiographs of horizontal planes (Planes H-H in Figures 70 to 75).
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Area projected onto plane normal to velocity.
(6) Obliquity is angle between velocity and target surface.

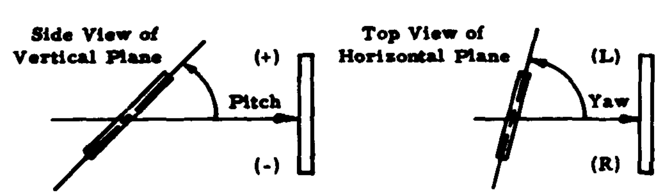


Table 11. Experimental Results, Copper Projectiles Fired at 90° Obliquity(6) Into 0.100-inch Thick 2024-T4 Aluminum Target Plates

Test No.	Fig. No.	Designation	Projectile: Length (in.)	Projectile: Diameter (in.) (1)	Projectile: Mass (grains)	Projectile: Velocity (ft/sec)	Orientation: Pitch (2)	Orientation: Yaw (3)	Orientation: Angle of Incidence (4)	Projected Area (in.^{2}) (5)	Target Damage (Crater/Hole Dimensions): Depth (in.)	Target Damage: Diameter (in.)	Target Damage: Area (in.^{2})	Target Damage: Vol. (cm^3)	Pressure mm/Hg
M-328	78	F	0.18	0.09/0.13	4.1	25,400	-70°	30°L	20°	0.022	Thru	0.48	0.18	NA	2.0
M-357	--	A	0.30	0.09	4.5	29,600	5°	0°	85°	0.009		0.52	0.21		
	--	C	0.13	0.10/0.71	1.6	29,400	0°	90°R	1°	0.010		0.39	0.12		
	78	X	0.16	0.09/0.07	1.9	26,000	-64°	68°R	17°	0.013		0.32	0.08		
M-359	78	G	0.27	0.05/0.04	1.0	25,800	-70°	76°R	12°	0.012		0.45	0.16		
	78	L	0.15	0.06	0.9	25,300	44°	68°R	21°	0.007		0.42	0.14		
	78	M	0.19	0.05	0.9	25,100	88°	83°R	2°	0.009		0.48	0.18		
M-360	78	Y	0.16	0. 0.08	2.0	26,100	50°	46°L	32°	0.015		0.44	0.15		
M-506	79	A	0.50	0.09/0.11	8.3	26,000	29°	15°L	58°	0.027		0.56	0.25		
	79	C	0.12	0.06/0.07	1.0	25,500	-66°	0°	24°	0.009		0.34	0.09		
	79	D	0.44	0.06/0.07	3.5	25,200	-19°	28°R	58°	0.017		0.42	0.14		
M-509	79	B	0.48	0.08/0.07	4.9	27,100	- 1°	44°R	46°	0.026		0.46	0.17		
M-516	80	X	0.22	0.12/0.08	4.0	26,200	-41°	9°L	48°	0.021		0.53	0.22		
M-517	80	X	0.11	0.05/0.06	0.6	25,700	2°	4°L	86°	0.003		0.19	0.03		
M-518	80	X	0.22	0.07/0.08	2.2	26,000	15°	10°R	72°	0.009		0.34	0.09		
M-519	80	A	0.31	0.09/0.11	5.4	26,300	89°	86°L	1°	0.031		0.56	0.25		
	80	B	0.26	0.05/0.07	1.6	26,100	33°	28°R	50°	0.011	Thru	0.40	0.13	NA	2.0

(Continued on next page.)

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes. (Planes V-V in Figures 78 to 84).
(3) Yaw is measured from top view radiographs of horizontal planes. (Planes H-H in Figures 78 to 84).
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Area projected onto plane normal to velocity.
(6) Obliquity is angle between velocity and target surface.

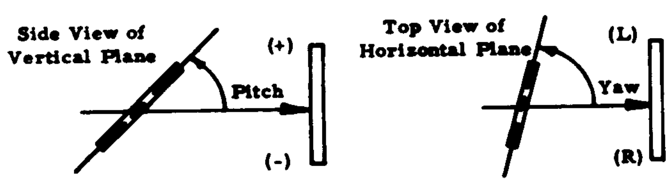


Table 11 (Cont'd). Experimental Results, Copper Projectiles Fired at 90° Obliquity[6] Into 0.100-inch Thick 2024-T4 Aluminum Target Plates

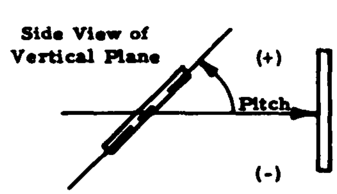
Test No.	Fig. No.	Desig-nation	Projectile: Length (in.)	Projectile: Diameter (in.) (1)	Projectile: Mass (grains)	Projectile: Velocity (ft/sec)	Orientation: Pitch (2)	Orientation: Yaw (3)	Orientation: Angle of Incidence (4)	Projected Area (in.^{2}) (5)	Target Damage (Crater/Hole Dimensions): Depth (in.)	Diameter (in.)	Area (in.^{2})	Vol. (cm^3)	Pressure mm/Hg
M-520	81	A	0.29	0.05/0.08	2.2	25,900	53°	18°L	36°	0.017	Thru	0.45	0.16	NA	2.0
	81	B	0.30	0.07/0.08	2.7	25,900	-37°	13°L	52°	0.015		0.42	0.14		
M-530	81	A	0.29	0.06/0.08	2.7	26,100	19°	45°L	43°	0.016		0.39	0.12		
M-659	81	A	0.56	0.10/0.09	9.6	30,000	-46°	63°R	25°	0.051		0.71	0.40		
	81	B	0.29	0.07	2.5	29,900	29°	40°L	49°	0.016		0.60	0.28		
M-668	82	X	0.25	0.08/0.04	1.4	31,900	- 3°	6°L	83°	0.010		0.19	0.03		
M-672	82	B	0.21	0.06/0.09	2.0	25,700	- 8°	62°L	80°	0.018		0.37	0.11		
	82	D	0.32	0.06/0.08	2.7	25,400	11°	9°R	28°	0.015		0.32	0.08		
M-675	82	A	0.51	0.11/0.10	10.3	26,900	8°	6°R	76°	0.009		0.46	0.17		
M-677	81	A	0.41	0.09	6.0	25,700	83°	75°L	4°	0.036		0.63	0.31		
M-679	82	C	0.13	0.05/0.06	0.7	25,300	84°	51°L	6°	0.007		0.36	0.10		
M-680	83	B	0.18	0.07/0.05	1.3	25,500	77°	5°L	13°	0.012		0.42	0.14		
M-681	83	X	0.28	0.07/0.06	2.2	26,400	-35°	66°R	23°	0.017		0.44	0.15		
	83	Z	0.28	0.07	2.7	26,200	28°	60°L	29°	0.019		0.53	0.22		
M-755	84	A	0.46	0.11/0.12	10.1	26,300	80°	90°	1°	0.050		0.70	0.39		
	84	C	0.33	0.08/0.06	2.8	26,100	90°	86°L	1°	0.022		0.58	0.26		
	84	D	0.29	0.06/0.08	2.3	25,600	-12°	40°L	49°	0.014	Thru	0.42	0.14	NA	2.0

Table 12. Experimental Results, Copper Projectiles Fired at 90° Obliquity(6) Into 0.500-inch Thick Soft Copper Target Plates

Test No.	Fig. No.	Designation	Projectile: Length (in.)	Projectile: Diameter (in.) (1)	Projectile: Mass (grains)	Projectile: Velocity (ft/sec)	Orientation: Pitch (2)	Orientation: Yaw (3)	Orientation: Angle of Incidence (4)	Projected Area (in.²) (5)	Target Damage (Crater/Hole Dimensions): Depth (in.)	Target Damage: Diameter (in.)	Target Damage: Area (in.²)	Target Damage: Vol. (cm³)	Pressure mm/Hg
M-756	85	B	0.08	0.07	0.7	22,900	-13°	90°	1°	0.001	0.25	0.45	0.16	0.53	2.0
	85	C	0.33	0.08	3.5	22,700	-29°	77°L	13°	0.025	0.48	0.67	0.35	1.58	↑
	85	D	0.25	0.08/0.10	3.4	22,600	-85°	67°L	5°	0.021	0.45	0.61	0.29	1.39	
M-759	85	X	0.09	0.05/0.04	0.3	26,400	38°	16°L	50°	0.004	0.16	0.30	0.07	0.17	
M-760	86	B	0.17	0.07/0.04	0.9	25,700	-79°	54°L	11°	0.009	0.29	0.53	0.22	0.78	
M-761	88	B	0.24	0.05/0.07	1.4	26,700	-15°	38°L	50°	0.009	0.32	0.55	0.24	1.18	
M-762	85	X	0.26	0.06	1.8	26,000	-87°	83°L	3°	0.016	0.22	0.45	0.16	0.48	
M-764	85	X	0.17	0.09/0.06	1.5	26,200	61°	48°R	25°	0.012	0.28	0.48	0.18	0.51	
	85	Y	0.17	0.06/0.10	1.9	26,200	17°	56°R	33°	0.013	0.25	0.54	0.23	0.85	
M-782	87	X	0.41	0.05/0.06	2.6	26,000	-70°	88°R	2°	0.024	0.31	0.66	0.34	0.99	
	87	Q	0.35	0.07/0.54	2.5	26,500	60°	39°L	28°	0.020	0.34	0.65	0.33	1.35	
	87	K	0.28	0.06	1.8	26,300	-38°	87°R	3°	0.016	0.27	0.54	0.23	0.76	
M-815	--	C	0.32	0.07	3.0	26,100	-46°	38°R	28°	0.021	0.33	0.59	0.28	1.15	
	--	D	0.13	0.07/0.05	0.8	25,900	8°	6°L	80°	0.004	0.28	0.39	0.12	0.58	
	--	E	0.16	0.07	1.4	25,600	- 1°	20°L	70°	0.007	0.37	0.49	0.19	1.00	
M-816	88	C	0.34	0.05/0.09	3.0	2[illegible].500	79°	35°L	11°	0.022	0.28	0.55	0.24	0.82	
	88	D	0.22	0.07/0.06	1.7	25,200	-44°	4°L	46°	0.012	0.41	0.53	0.22	1.10	
M-817	88	D	0.25	C 08/0.06	2.1	26,100	4°	4°L	84°	0.005	Thru	0.54	0.23	----	
	88	E	0.30	0.07/0.06	2.4	25,600	11°	62°R	28°	0.017	0.28	0.49	0.19	0.82	↓
	88	F	0.17	0.06	1.2	25,500	-23°	24°L	58°	0.008	0.28	0.54	0.16	0.66	2.0

(Continued on next page.)

Notes:
(1) Where two values are given, the projectile is elliptical in cross-section, and dimensions are measured along major and minor axes.
(2) Pitch is measured from side view radiographs of vertical planes.
(3) Yaw is measured from top view radiographs of horizontal planes.
(4) Angle of Incidence: Angle between major axis of projectile and target.
(5) Area projected onto plane normal to velocity.
(6) Obliquity is angle between velocity and target surface.



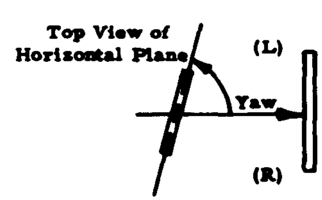


Table 12 (Cont'd). Experimental Results, Copper Projectiles Fired at 90° Obliquity[6] Into 0.500-inch Thick Soft Copper Target Plates

Test No.	Fig. No.	Desig-nation	Projectile: Length (in.)	Diameter (in.) (1)	Mass (grains)	Velocity (ft/sec)	Orientation: Pitch (2)	Yaw (3)	Angle of Incidence (4)	Projected Area (in.²) (5)	Target Damage (Crater/Hole Dimensions): Depth (in.)	Diameter (in.)	Area (in.²)	Vol. (cm³)	Pressure mm/Hg
M-855	88	X	0.28	0.06/0.07	1.8	25,800	-66°	88°L	2°	0.016	0.34	0.56	0.25	0.90	2.0
M-861	89	C	0.24	0.08/0.05	1.7	25,900	-19°	49°R	40°	0.013	0.29	0.52	0.21	0.70	
M-862	89	X	0.17	0.06/0.05	1.0	25,900	22°	70°R	20°	0.009	0.24	0.54	0.16	0.49	
M-863	90	X	0.21	0.09/0.07	2.4	26,100	-34°	4°R	56°	0.012	Thru	0.59	0.27	----	
	90	Y	0.23	0.07/0.06	1.7	26,000	17°	42°R	46°	0.012	0.28	0.59	0.27	0.73	
	90	Z	0.28	0.07/0.09	3.2	25,500	-64°	88°R	2°	0.021	0.31	0.63	0.31	0.85	
M-865	--	X	0.39	0.08/0.06	3.7	25,400	-56°	88°R	2°	0.027	0.30	0.59	0.28	0.86	
M-866	--	X	0.20	0.05/0.08	1.5	25,800	38°	65°R	24°	0.013	0.28	0.48	0.18	0.81	
	--	Y	0.19	0.06/0.07	1.6	25,500	66°	7°L	24°	0.011	0.28	0.48	0.18	0.84	2.0

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Unclassified Report

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1. Shaped charges
2. Hypervelocity projectiles
3. Penetration
4. Impact shock
5. Accelerators

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II. Contract AF 08(635)-975
III. Aerojet-General Corp., Downey, Calif.
IV. Ferguson, J. E.
V. In ASTIA collection

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